Theme 3
Vision 2047

MOUNTAIN HYDROLOGY AND SPRINGSHED MANAGEMENT

SPRING OUTFLOWS IN DIVERSE LITHOLOGICAL AND GEOMORPHOLOGICAL SETTINGS OF MID-HILL REGION OF WESTERN NEPAL

Gunanidhi Pokhrel[1*], Moti Lal Rijal[1] and Gopal Krishan[2]

[1]Central Department of Geology, Tribhuvan University, Nepal
[2]National Institute of Hydrology, Roorkee (Uttarakhand), India
[*]Corresponding author e-mail: gunanidhi.785707@iost.tu.edu.np

The most springs are drying up and declined their water outflow in the non-snow fed watersheds of mid-hill region in Nepal, which is leading to water scarcity. The water related issues are directly affecting the community's livelihood and overall ecosystem. This study aims to understand the springs characteristics and analyze the spring discharge variations between the two high flow seasons based on parameters such as lithology, occurrence, elevation, landform, and land cover. This study highlights the importance of understanding landform-specific spring water flow dynamics for water resource management and planning, especially in regions with high seasonal variability.

The study area Seti Khola watershed is located in the mid-hill of western Nepal within Parbat and Syangja districts, which is about 115 km^2. During fieldwork, spring locations were explored and assessed through transect walks conducted with the assistance of community resource persons. Altogether, 168 perennial springs were identified over seasonal springs after the compilation of databases of high and low flow season. Among spring inventories, high flow periods of two consecutive years 2022 (Y1) and 2023 (Y2) were conducted, respectively. Several methods were used depending on the spring type and available kits such as bucket and stopwatch method for minimal discharge (MND), weir and float method for intermediate discharge (ID) and maximal discharge (MXD). The percentile-based discharge classification established for lower 25% of the values as MND, middle 50% of data as ID and upper 25% of the values as MXD.

Springs were inventoried gathering spatial distribution and societal information. The households and socio-economic information about the springs were obtained from the permanent residents of the local community. The spatial distribution of springs was analyzed using lithological and geomorphological data. The lithological data was extracted from the latest published literature published in the Bulletin of Central Department of Geology and added from the field observations, which is then simplified as carbonate and non-carbonate lithology. The geomorphological parameters such as elevation classes derived from a 5-m DEM were categorized into three groups: Class I (below 1000 m), Class II (1000–1500 m), and Class III (above 1500 m above mean sea level (amsl)). Soil data from SOTER were classified into Eutric Cambisols (CMe), Chromic Cambisols (CMx), and Gleyic Cambisols (CMg). Similarly, land cover from FRTC data included forest, grassland, and cropland. The site-specific occurrence of springs was categorized by depression spring, fracture spring, karst spring, and rock-sediment spring.

Local communities indicated complete reliance on spring water for their livelihoods and daily needs, emphasizing the vital role these sources play in maintaining the flow of their rivers. Seti Khola originates from springs during dry period and surplus contribution of rainfall during wet season in the region that flows across the varieties of rock types and landforms from northeast to southwest. Geologically, the area lies within the Tansen Group, Sirkot Group, Upper Nawakot Group and Lower Nawakot Group. About 44% of the area consists of Carbonate rocks while the remaining 56% are non-carbonate rocks regardless of thin carbonate bands of thickness in few mm to cm. The major rock types in the study area are Dolomite, Limestone, Quartzite, Slate and Phyllite. The carbonate springs consistently have higher discharge compared to non-carbonate springs across seasons. The carbonate terrain had an accumulated discharge of 3549.03 lpm, exceeding the non-carbonate discharge of 2682.29 lpm by 866.74 lpm in Y1 whereas in Y2, both decreased, with carbonate at 3033.79 lpm and non-carbonate at 2428.18 lpm, a difference of 605.61 lpm.

The occurrence of springs is high in 15-30° slope and 1000-1500 m amsl. The analysis shows that ID is the most frequent across both seasons, especially in elevation Class II. The MXD is uncommon, particularly absent in Class I, with a slight decrease from Y1 to Y2. The MND increases in Y2, in Class II and Class III, suggesting seasonal flow reduction. The elevation Class II consistently experiences the highest water flow across discharge categories, while Class I shows the lowest, particularly for MXD. The forest areas dominate in all discharge classes, with ID being the most frequent in both Y1 (55 springs) and Y2 (52 springs). The MND increases from Y1 (61 springs) to Y2 (67 springs), particularly in Forest and Cropland. The springs with MXD is rare, with less counts across land types and a slight decrease from Y1 (25 springs) to Y2 (22 springs). Grassland consistently shows the lowest counts across all discharge categories.

Fracture springs and rock-sediment interface springs are key to maintaining ID and MXD, due to their geological characteristics allowing water movement. Depression springs, on the other hand, show vulnerability to MND, indicating poor outflows or slower recharge rates. Seasonal shifts, particularly reductions in MXD from Y1 to Y2, reflect environmental factors. The Eutric Cambisols dominate both ID and MXD, with 53 springs in Y1 and 50 springs in Y2 for ID, and 19 springs and 18 springs for MD, reflecting their high fertility and good outflows. Chromic Cambisols contribute consistently to ID (25 springs in both seasons) and MND (increasing from 14 to 16 springs), indicating stable but less frequent water flow. Gleyic Cambisols, due to their poor outflows, have minimal contributions across all categories, particularly MXD, with no spring counts. CMe keeps the widest range of water outflows, while CMg reduces discharge.

The study reveals that the ID is the most frequent in both Y1 and Y2 (~ 48%). MXD has the least number of springs (~ 14%), decreasing across seasons, indicating its rarity and potential seasonal influence. MND has about 38% springs increases in Y2, especially in non-carbonate areas, reflecting seasonal water flow shifts where the non-carbonate regions consistently show higher ID. Spring usage in the region shows MND supports soil moisture retention, ID aids local water supply, and MXD is essential for large-scale supply and ecosystem health, emphasizing their hydrological importance. Forest areas experience the most significant water flow variations, followed by cropland, while grassland shows minimal variation. Overall, water flow tends to diminish from Y1 to Y2, due to seasonal factors such as reduced rainfall and increased evaporation.

***Keywords**: Springs, spring discharge, carbonate rocks, elevation, soil and landcover*

DISTRIBUTION OF SPRINGS ALONG THE PHALEBAS THRUST IN MIDDLE HILL REGION OF WESTERN NEPAL

Nirajan Ojha*, Susan Shakya, Gunanidhi Pokhrel and Moti Lal Rijal

Central Department of Geology, Tribhuvan University Nepal
**Corresponding author e-mail: nirajanojha77@gmail.com*

Springs play a crucial role as to fulfil fresh water demand of local communities situated in dispersed settlements situated in the middle hill region of the Nepal Himalaya. The study investigates the significant influence of the Phalebas Thrust on the distribution and discharge variabilities of springs in the study area. The study area is located in the Syangja District of Western Nepal with area coverage of 28.53 km^2. The study area includes varied topography with elevations ranging from 780 to 2008 m above mean sea level (amsl) in the sub-tropical climate with average annual precipitation 2426.1 mm and dominated with dendritic drainage pattern. The study area includes various metasedimentary formations of the Lesser Himalayan Sequence, which significantly influence groundwater dynamics. The major geological structure of the region is the Phalebas Thrust, which runs southwest-northeast across the study area. The thrust plays a crucial role in controlling the spatial distribution of springs, as the fracture networks associated with the thrust provide pathways for groundwater movement. The study also examines the role of thrust-induced fractures and joint networks in facilitating groundwater flow, thus impacting the frequency and discharge of springs.

A systematic spring inventorization was conducted as part of this research, utilizing both primary and secondary data. The spring inventory, which involved direct field observations with the assistance of local resource person. Geological data, including bed orientations and lithology, were collected from field survey. In addition, spring discharge was measured using the volumetric method, which involves calculating the time taken to fill a calibrated container. The geological formations of the area were classified based on lithology, whereas the proximity of springs to the Phalebas Thrust was analysed in intervals of 100 meters as of Euclidean distance. The geological formations of the study area are part of the Upper and Lower Nawakot Groups, consisting of the Benighat Slates, Dhading Dolomite, Nourpul Formation, Nayagaun Formation, Naudanda Quartzite and Kuncha Formation. The study area is highly deformed, with numerous thrusts and folds contributing to the geological complexity. From this study, it revealed that there is a total of 92 perennial springs within the study area. These springs were classified into different types based on their origin, including depression, fracture, fault, karst and contact springs. The highest spring density was observed within 0 to 100 m of the Phalebas Thrust, highlighting the significant influence of the thrust on groundwater flow. Springs in the area were predominantly found in carbonate terrains, where dolomitic formations contribute to higher discharge rates. Notably, the Dhading Dolomite exhibited the highest spring discharge, with one of the largest springs having discharge rate of 39.79 lpm.

The findings of this study have important implications for groundwater management in the middle hill region where there is a significant role of not only lithology but also of geological structure. The high concentration of springs near the Phalebas Thrust indicates that geological structures, particularly thrust zones, play a critical role in determining groundwater availability. The data also suggest that the interaction between geological contacts and thrust-related fractures significantly influences spring discharge. Approximately 62% of the total spring discharge in the study area is contributed by springs located within 400 meters of the Phalebas Thrust. The study also highlights the influence of topography on spring distribution. Springs were found to occur at various slope angles, with the majority located on moderate slope range between 15° to 25°. The springs were also distributed according to aspect, with a significant concentration on south-east facing slopes. These findings suggest that topographic factors, in combination with geological structures, play an important role in determining the location and behaviour of springs in the region. The geomorphology of the area further impacts groundwater flow, particularly in the southern part of the study area, where karst features are prominent. The karst geomorphology, characterized by soluble rock dolomite, creates conditions that enhance secondary porosity and permeability, allowing for increased groundwater flow. This is reflected in the higher discharge rates observed in springs located in dolomitic terrains. The study found that the majority of the springs with high discharge rates were located in these karstic areas, further emphasizing the importance of geological formations in controlling groundwater behaviour.

The study underscores the critical role of geological structures, especially thrust zones, in shaping the distribution and behaviour of springs. The Phalebas Thrust, in particular, plays a significant role in controlling the occurrence and discharge of springs, with higher spring density and discharge rates observed in the periphery of the thrust alignment. Approximately, 23% of the springs are located within 100 meters of the thrust alignment, with a gradual decrease in spring frequency observed as the distance from the thrust alignment increases. The lithology proximity to the thrust, Benighat Slates has highest number of springs and higher amount of discharge with respect to the area of the geological formation. These findings have important implications for the sustainable management of groundwater resources, especially management of springs and their springsheds in the Himalaya. This study clearly emphasizes that a proper understanding of geology and hydrogeological settings of any study area is a key to address spring hydrogeological issues, which can also provide fundamental knowledge about drying springs in the middle hill region of the Nepal Himalaya.

Keywords**:** *Phalebas Thrust, lithology, springs, discharge, middle-hill*

STAGE-DISCHARGE RATING CURVE AND PARTICLE-SIZE DISTRIBUTION OF SEDIMENT OF RANIKHOLA RIVER, SIKKIM, INDIA

Ankit[1], S.R. Yadav[2*] and Shivam[2]

[1]*Department of Soil and Water Conservation Engineering, College of Agricultural Engineering & Post Harvest Technology, (Central Agricultural University, Imphal, Ranipool, Sikkim, India*
[2]*Faculty of College of Agricultural Engineering & Post Harvest Technology, Central Agricultural University, Imphal, Ranipool, Sikkim, India*
[*]*Corresponding author e-mail: sryadav52@gmail.com*

During the rainy season, river streams in Sikkim have high runoff volumes and flow velocities, requiring periodic measurement of river stage and discharge. The Teesta River, the most important in Sikkim, covers the entire state and tributaries include the Ranikhola River. River discharge measurement is crucial for hydrologic and hydraulic design, as it aids in planning and managing water resources. It is estimated through cross-sectional area and velocity measurements, and is linked to water surface elevation, known as stage, using the rating curve. The rating curve is a crucial tool in surface hydrology, as its reliability relies on a satisfactory stage-discharge relationship at the gauging station. It is also very important in the validation and calibration of rainfall-runoff and flood routing models. Therefore, it was felt necessary to develop a rating curve for the *Ranikhola* River, one of the major tributaries of Teesta River in Sikkim.

River-suspended sediment concentrations are crucial for pollution, channel navigation, reservoir filling, and fish habitat. Sedimentation, a weathered material, is used in erosion hazards evaluation, water resource management, and dam design. Reservoirs created by dams receive silt, reducing water storage space and reducing benefits. Siltation can also cause increased evaporation losses, backwater flooding, and damage to powerhouse turbines. Sedimentation transport occurs in two forms: bed load and suspended load. Bed load is the coarser fraction of sediment, while suspended load is the fine-grained sediment that remains in water during transportation. The amount of load carried depends on the stream's volume, velocity, disintegrated materials, vegetative cover, and stream bed. The study aims to estimate the rate of sedimentation in the Ranikhola River, a mountainous stream, by collecting weekly water samples, estimating suspended load, and estimating bed load. The study also considers human activities along stream banks, such as sand quarrying operations, land clearing, and landslides, which affect sedimentation rates.

Particle-size analysis is a crucial tool in soil science to assess soil texture, which is determined by the distribution of sand, silt, and clay particles in a soil sample. Mechanical analysis, which involves the separation of soil into different size fractions, is performed in two stages: sieve analysis for coarse-grained soil and sedimentation analysis for fine-grained soils. In this study, various methods for calculating different parameters in the field as well as in the laboratory have been discussed. The various parameters are stage flow, velocity and discharge of the *Ranikhola* river at cross-sections, sediment rate at the same cross-sections, and channel scouring and braiding of the mountain streams. To derive the stage-discharge rating curve, the flow velocity and cross section of the river at the various sections were estimated. The section chosen was such that it is easily accessible in the time of flood. One site was selected on the *Ranikhola* river and other one at Hanging bridge to establish stage-discharge rating curve and sediment analysis. The Hanging bridge was selected to study the

scouring and braiding in the *Ranikhola* river. For establishing stage-discharge rating curve, the selection of the site was such that the cross-section does not change with time. Stage-discharge rating curve was created by plotting the stage and accompanying discharge values on arithmetic and logarithmic scales.

In this study, river water samples were collected on the regular basis from the Hanging bridge section on the *Ranikhola* by using plastic sampling bottles. The particle size distribution analysis of the sediment samples in the *Ranikhola* river can be established by sieve analysis. The braiding analysis was performed to check the change in the river bed. The river stage and corresponding discharge was taken on the *Ranikhola* river in Sikkim for 1-month duration. The measured stage was plotted against the observed discharge on the arithmetic and logarithmic plots with stage as ordinate and discharge. The coefficient of determination (R^2) was observed to be 0.94. The corresponding logarithmic equation for the *Ranikhola* river equation can be used to compute the flow discharge in the *Ranikhola* river for the measured stage near hanging bridge cross-section. The total sediment load in the *Ranikhola* river ranged between about 1.1 to 7995 tonnes/day at the hanging bridge section. The highest sediment rates were found to be on April 07, 2022.

The particle size distribution curve for the sediment sample collected at the upstream side of the hanging bridge cross-section on the *Ranikhola* river. The percentage of gravel is 46% sand is 54 %, Coefficient of Uniformity Cu = 18.88, Coefficient of curvature Cc = 0.56. The sediment is classified as well graded sand. As per USDA textural soil classification system, it is observed that the sediment comprises of 69.2%, 27.2% and 3.6% of clay, sand and silt, respectively and as per USDA, it can be classified as clay soil. As per ISSS classification system, it is observed that the sediment comprises of 69.2%, 30.6% and 0.2% of clay, sand and silt, respectively and it can be classified as clay. The hydrometer analysis showed that the river sediment mostly contains clay as per both soil classification systems. The braiding analysis was done for the same section of the *Ranikhola* river for different dates at 1 m, 2 m and 3 m distance from the left water edge. It can be observed that the river bed depth in the stream apart from the section below the bridge changes significantly. For e.g., the channel bed gets deposited during the high flows on 07/04/2022 by about 17 cm at 1 m distance and 5 cm at 2 m distance, whereas at 3 m distance, the scouring of 8 cm has been observed. As compared to the channel banks, more scouring has been observed near the centre of the flow. It can be reveals from 3 bars of the diminishing sizes on 12/04/2022 with braiding depths of 23 cm, 3 cm and 1 cm at the distance of 1 m, 2 m and 3 m, respectively. The developed stage-discharge rating curve equation ($h = 0.2953 \ln(Q) + 821.87$) can be used to estimate discharge in the *Ranikhola* river from measured stages. The range of sediment discharge in the *Ranikhola* river is observed to be 1.1 to 7995 tonnes/day. It can be concluded that as the flow discharge reduces, the braiding of the channel bed increases near the stream banks as conferred to that near the flow centre. This may be attributed to the human activities like sand quarrying, land clearing for buildings, landslide, etc. Thus, channel braiding analysis leads to the conclusion that the river bed varies considerably, sighting that a considerable scouring and deposition. The large sediment inflow in the *Ranikhola* River necessitates large scale catchment area treatment programmes including structural and non-structural control measures in the watershed area of the river.

Keywords: *Stage-discharge, sedimentation, particle size distribution, channel braiding*

SPATIO-TEMPORAL DISTRIBUTION OF NATURAL WATER RESOURCE IN KANGRA BLOCK, HIMACHAL HIMALAYA: A HYDROCHEMICAL AND HYDROLOGICAL ANALYSIS

Shikha Rawal[1], P.G. Jose[2] and Anurag Linda[1*]

[1]*Department of Environmental Sciences, Central University of Himachal Pradesh, India*
[2]*Western Himalayan Regional Centre (WHRC), Jammu, National Institute of Hydrology, India*
[*]*Corresponding author e-mail: anurag.linda@cuj.ac.in*

Groundwater is a valuable resource for various domestic uses, including irrigation, drinking, and manufacturing deeds. The main components of groundwater research emphases on its quality and quantity. The hydrochemical study determines whether the water is safe to drink, while assessing water amount ensures its availability for future necessities. Changes in quality or quantity are primarily impacted by rock-water interactions, climate inputs, and human activities. The sustainable growth requires an effective management of natural water resources. Springs, a major source of freshwater, serve an important role in supporting several people throughout the Indian Himalayan region. However, rising freshwater demand, along with rapid population increase, shifting weather patterns, and different development activities such as contemporary agricultural methods, industrialization, and urbanization has resulted in major changes in land use and cover. These changes have degraded spring ecosystems, impacting both water quality and availability. These changes have adversely affected spring habitats, reducing both water quality and availability. Addressing the numerous issues of drying springs or declining volume in hills requires a thorough investigation of both socioeconomic and biophysical factors, as well as their relationships. This can be accomplished through cohesive study that actively engages local communities or end users. Spring discharge is directly related to the recharge area characteristics, such as shifts in rainfall patterns, changes in land use or cover, and the aquifer ability to store and transmit groundwater. Each spring is unique in terms of its type, catchment area, form of discharge, terrain, and geological structure under the surface. The change in rainfall patterns in the Himalayas not only influences the water supply and livelihoods, but it also causes challenges for downstream communities. To assess the utility of these fresh water sources for domestic purposes, a total of 21 spring water samples were collected during pre- and post-monsoon seasons (2021-2022) in the Kangra block of Himachal Pradesh. Different geochemical modeling tools, multivariate statistical analysis, and graphical plots were employed to comprehend the major geochemical processes and the impact of anthropogenic forcing on spring water chemistry. The collected samples were analyzed for various water quality characteristics along with their discharge pattern and further compared with Bureau of Indian Standards (BIS). Spring discharge was measured periodically (once in a month) where measuring locations referred to as spring sites, which are natural outlet channels or man-made outflows such as plastic or metal pipes. The discharge was further calculated by using Time Volume Method, where flow (Q) can be captured into a container of known volume (V), one of the most straight forward methodologies for determining discharge is to time (t) the filling of the container and calculate the water flow from springs i.e. $Q=V/t$. The most abundant cations were found to be Ca^{2+}, Mg^{2+}, Na^{+}, & K^{+} followed by Cl^{-}, SO_4^{3-}, NO_3^{-}, & F^{-} as predominant anions. The analyzed chemical composition of springs met the standard criteria for drinking water quality by BIS. Nevertheless, the physicochemical characteristics of the spring water were found to be varied both spatially and seasonally. The chemical analysis obtained for most of the samples reveals CBE levels of about ±10%. The results from bivariate plots and PCA indicate that the lithological characteristics with some extent to anthropogenic inputs are the dominant processes controlling the chemical evolution of spring water in the region. The selected parameters were all under the permissible limits therefore the collected samples were of good quality and suitable for human consumption, however prior treatment of water is advised before consumption. The mean spring discharge peaked at 25 Lt/m during post monsoon and further diminishes to 1.5 Lt/m during pre-monsoon. The spring discharge exhibits an annual, periodic rhythm which is significantly impacted by rainfall patterns with discernible time lags. Even though the variations in ionic concentration of springs are observed, which might be season-specific. However, it is equally important to have further studies regarding total coliform, heavy metal, and pesticide pollution to reach at better and holistic understanding of the water quality of these springs. The study reveals that the hydrochemical composition of spring water is influenced not only by geogenic processes, such as rock-water interactions, but also by anthropogenic activities in the region. Findings indicate that springs located near settlements are more susceptible to contamination from human activities, while those in sparsely populated areas face the risk of depletion due to inadequate catchment management and sanitation practices. Additionally, a noticeable decline in water discharge during the summer season is linked likely to ongoing development activities in the area. However, rising temperatures and precipitation variability caused by climate change have aggravated the spring water catchment areas. A comprehensive hydrogeological mapping of the spring shed endeavor is designed to identify unique recharging zones and aquifer interferences. It also contributes to a better understanding of aquifer hydrodynamics and water storage-discharge interactions. This study provides valuable baseline data on spring water availability and accessibility, facilitating better management of these critical groundwater sources during essential periods. Moreover, it contributes to a deeper understanding of the region's microclimatic conditions.

Keywords: *Natural resources, springs, water quality, water discharge, sustainability, longevity*

TRACING SOLUTE SOURCES AND DERIVATION PATHWAYS IN TRANS – HIMALAYAN GROUNDWATERS OF THE INDUS RIVER BASIN IN LADAKH, INDIA

Poulomee Coomar[1]*, Suhail Ahmed Lone[2], Gh. Jeelani[2], Dewashish Upadhyay[1], Saibal Gupta[1], and Abhijit Mukherjee[1,3]

[1]*Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, India*
[2]*Department of Earth Sciences, University of Kashmir, India*
[3]*School of Environmental Science and Engineering, Indian Institute of Technology, Kharagpur, India*
[*]*Corresponding author e-mail: rimpakoomar@gmail.com*

Observed groundwater chemistry of a region is the result of several inter-related factors: precipitation chemistry, water – aquifer matrix (rock) reactions, mixing with other sources of water, and anthropogenic disturbance. Of these, the type and intensity of water, rock interactions are perhaps the most important, given the differential solubilities and dissolution rates of minerals, especially in a multi-lithology terrain. Although solute sources and release mechanisms to groundwater are well established in the middle and lower transboundary Indus River basin aquifers, such delineations are relatively scarce in its mountainous stretches. The present study aims to delineate these processes and the sources of solutes in the upper Indus River basin in Ladakh, India, through geochemical mass balancing, thermodynamic (saturation indices calculation, stability diagram, phase diagrams), statistical approaches and $^{87}Sr/^{86}Sr$ isotopic systematics.

The study has been conducted for the Union Territory of Ladakh, India, between north latitudes 33° 40’ N and 35° 0’ N and east longitudes 75° 29’ and 78° 10’ E, covering an area of 36,000 km^2 of the Leh and Kargil districts. The region experiences a cold-arid climate. Geologically, the area can be divided into four tectono - stratigraphic zones. From SW to NE these are: Zanskar Zone, Indus-Tsangpo Suture Zone (ITSZ), Shyok Suture Zone (SSZ) and the Karakoram Zone. Groundwater samples were collected from bedrock and over-burden aquifers across four tectono–stratigraphic units of the ITSZ namely: Dras volcanics (DV), Indus Formation (IF), ophiolitic mélange (OM), Ladakh Plutonic Complex (LPC), and the SSZ. Samples were collected from hand-pumps and tube wells after sufficient flushing and field readings were noted. Collected samples were preserved and analyzed for major, minor, and trace solutes and $^{87}Sr/^{86}Sr$ ratios. Cations were analysed in the ICP-OES and anions in an ion chromatograph. For $^{87}Sr/^{86}Sr$ analysis, approximately 2000 ng of Sr was extracted using the BioRad AG 50W 8X resin. Isotopic composition was measured in a MC – ICP - MS in static, multi - collector mode.

Groundwater aquifers are composed of fluvial, fluvio-glacial, aeolian, lacustrine sediments in river valleys and adjoining bedrocks, ranging in composition from ultrabasic to acidic and from carbonate to siliciclastic. Basic hydrogeochemical assessment reveals water temperature varies between 8 - 18°C. Waters are circum – neutral, mildly reducing to oxidizing, and are of Ca-HCO_3 and Ca-Mg-HCO_3 type. Waters plot in the rock weathering domain of the Gibbs Plot and seem to be affected by a combination of carbonate and silicate weathering. Cation exchange occurs minorly. Mass balancing predicts simultaneous dissolution of calcite and dolomite, incongruent dissolution of pyroxenes, feldspars, serpentine, olivine, biotite and chlorite to kaolinite, smectite, vermiculite, and illite. Thermodynamic calculations suggest that waters are sub to super saturated in calcite and quartz, undersaturated in amorphous silica, supersaturated in Fe oxy (hydr) oxides, in equilibrium with kaolinite, and in disequilibrium with feldspars and muscovite.

Groundwater Sr varies from 57 to 3416 µg/L and $^{87}Sr/^{86}Sr$ from 0.7075 to 0.7275. Strontium exhibits moderate positive correlations (with albeit scattering) with other solute parameters while, $^{87}Sr/^{86}Sr$ shows none. $^{87}Sr/^{86}Sr$ also doesn't correlate with 1/Sr and indicators of silicate weathering (SiO_2/TDS, Na* + K/ total cationic charge). Median groundwater Sr/Ca (6800 µg Sr/g Ca) and $^{87}Sr/^{86}Sr$ (0.711) ratios are significantly higher than those of typical carbonates (Sr/Ca: 1000 - 2000 µg/g; $^{87}Sr/^{86}Sr$: 0.707–0.709) suggesting a major input from silicate sources. Groundwater $^{87}Sr/^{86}Sr$ ratios in the IF, LPC, and OM aquifers matches well with the whole-rock $^{87}Sr/^{86}Sr$ ratios of these units, suggesting derivation of solutes from them. However, $^{87}Sr/^{86}Sr$ of DV and SSZ waters are significantly higher than their bed rock values, suggesting prolonged interaction of recharge water with the more radiogenic over burden. $^{87}Sr/^{86}Sr$ signature suggests DV waters are deriving (at least a part) of their cationic budget from the Higher Himalayan Crystalline and Tethyan Sedimentary Sequences derived detritus brought in by the Dras and Suru rivers, while solutes sources to SSZ waters is the LPC.

The work suggests that the groundwater composition in the upper Indus River basin of Ladakh, India, is dominantly controlled by water-rock (aquifer matrix) interaction processes taking place within the subsurface. Although preliminary hydrogeochemical investigations suggest that the waters are affected by a dual carbonate-silicate weathering pathway, significantly higher groundwater Sr/Ca and $^{87}Sr/^{86}Sr$ ratios than those of typical carbonates, suggest a dominance of silicate weathering. Scattering in Sr–solute relationships, lack of a linear trend between 1/Sr and $^{87}Sr/^{86}Sr$ and correlations of $^{87}Sr/^{86}Sr$ with other solutes and indicators of silicate weathering indicate the existence of multiple silicate sources. A variety of silicate minerals, are predicted to weather to kaolinite, vermiculite and illite. Among mafic phases serpentine, olivine, chlorite, pyroxene, and biotite are deduced to be the main solute sources while both plagioclase and alkali feldspars constitute the felsic contributor pool. Groundwater $^{87}Sr/^{86}Sr$ ratios in LPC, IF and OM aquifers matches well with their aquifer matrix values establishing them as their solute sources. Strong mismatch between aqueous and solid phase $^{87}Sr/^{86}Sr$ signatures in DV and SSZ aquifers suggests that the solutes in them are derived from more radiogenic Himalayan sources. The work signifies, the role of weathered residuum and infiltration zone processes in controlling water chemistry of bedrock aquifer systems.

Keywords*: Ladakh, Indus River basin, groundwater, aquifers, Himalayan geology*

GRAVITY-BASED PRESSURIZED PIPE IRRIGATION NETWORKS (GPPINS) USING SPRINGS IN HILLY AREAS: OPPORTUNITIES AND CHALLENGES

Venkata Ramamohan Ramachandrula*

Water and Livelihoods Foundation (WLF), Hyderabad, Telangana
**Corresponding author e-mail: ramamohan.ramachandrula@gmail.com*

Most of the agriculture lands in hilly areas do not have any irrigation facility. Gravity piped irrigation networks (GPPINs) are generally feasible in hilly areas having perennial springs and surface streams. The GPPINs tap the water in a flowing stream at a certain height on the hill-tops and carry the water through a network of pipes until the delivery points, i.e., the individual lands of farmers. Unlike open channel flow, the water is mostly carried through underground pipelines. A low-head barrier across the stream at the source point is commonly used to rise the water level and divert the water into the pipeline. The water flows under pressure through the pipe network using the static energy of water at the source point. A typical GPPIN consists of five components, viz., water source, main pipeline, branch or sublines, individual delivery pipes and outlets, and minor components for regulation of water flow. The GPPINs typically follow a tree-and-branch type configuration. Based on the physical configuration and flow of water in the network, the GPPINs may be classified into two types, viz., open network and closed network. Open networks will be having main pipeline and all the branch pipelines plugged at their end points. The water will be either delivered through the outlets or remain in pipelines. On the other hand, the closed networks will have closing loops between selected ends of main or branch lines. In the case of open channel and open pipe networks, in the absence of extensive drainage channels, the excess water has to flow from the plot of land to the plot downstream. In contrast, GPPINs permit application of the required quantity of water for the selected crops, effectively preventing excess flow of water to downstream plots. Furthermore, GPPINs permit farmers to rotate crops seasonally as per the soil conditions, local climate and market demand. While farmers prefer to cultivate paddy during the monsoon season, they shift to short-duration less-water-intensive crops like vegetables, flowers, and tubers during winter and summer months. GPPINs deliver water across the command area, by laying of pipelines across undulating slopes as well as against falling slopes. There is no loss of land as most of the piping is done underground. The piping done using UPVC or HDPE (High-Density Polyethylene) lasts for 15–20 years.

Though, there are several advantages of GPPINS, they are not devoid of limitations and disadvantages. The GPPINS require skilled engineers and experienced workers to plan, design and construct them. Skillful pipeline alignment reduces capital costs on pipeline and improves the system performance in terms of lesser head-loss in pipes. The capital costs of GPPINS are relatively higher, though they come with durability and longer functional life. Often, transporting construction materials and machines to remote hill-tops become difficult due to the lack of motorable roads. Though the HDPE pipes cost 20-30% more than the UPVC pipes of the same diameter, HDPE pipes have several advantages. They may be bent easily to follow the curvature in pipeline alignment. HDPE pipes are available as rolls, for diameters up to 110 mm. Though the use of rolls has the definite advantage of reducing the number of joints and lesser time in pipe laying, transporting and handling of rolls of HDPE

pipe is more cumbersome. Pipe joints and valve connects are prone to leakages and breakages, if the GPPIN is designed for pressures more than 10 m at the outlets. Typically, joints between UPVC pipes and between HDPE and UPVC pipes may weaken over time and result in leaks. Such leaks lead to pressure-loss in the system and reduced discharge at some outlets. Therefore, it is important to attend to such minor repair and maintenance works as soon as they are noticed. There are no specific guidelines available for the planning and design of GPPINs in India. Based on the field experiences in India and Bhutan, the practical insights in designing gravity irrigation systems have been narrated here. Gradually falling land slope with an elevation difference of 30-40 m over a ground distance of 1.0-1.5 km between the stream source and the last point is ideal for building GPPINs. Maintaining a pressure of 7-10 m at each outlet point is desirable for optimum cost and performance. Closed-loop design always helps in equalizing the pressure from different outlets. The HDPE pipes emerge as the best choice for these networks owing to their flexibility, durability and ease in assembling of joints. Environmental Protection Agency Network Evaluation Tool (EPANET) software is very useful not only in the design of new GPPINs, but also in simulating the function of existing networks under different water demand scenarios. Overall, GPPINs have a high potential to meet the irrigation water needs of farm lands in many hilly areas, to boost the agricultural production and substantially increase the farm incomes of small farmers.

Keywords: *EPANET, gravity irrigation, irrigation network, pipe flow, hill springs*

INTEGRATING SCIENCE AND COMMUNITY ACTION FOR SUSTAINABLE SPRINGSHED MANAGEMENT IN THE INDIAN HIMALAYAS

Neeraj Pant[1,2*], Dharmappa Hagare[2], Basant Maheshwari[3], Megha Sharma[1], Shive Prakash Rai[4] and Jyothi Prasad[5]

[1] *Nehir Himalayan Sanstha, Almora, Uttarakhand, India*
[2]*School of Engineering, Design and Built Environment, Western Sydney University, Australia*
[3]*School of Water, Environment & Sustainability, Western Sydney University, Australia*
[4]*Department of Geology, Banaras Hindu University, Varanasi, Uttar Pradesh, India*
[5]*G. B. Pant University of Agriculture & Technology Pantnagar, Uttarakhand State, India*
[*]*Corresponding author e-mail: 19990385@student.westernsydney.edu.au*

The Hindu Kush Himalayan (HKH) region, often referred to as the "water tower of the Asia," plays a crucial role in providing freshwater to millions of people. However, this region is facing a growing challenge of water scarcity, exacerbated by a decline in spring discharge. This decline can be attributed to a combination of factors including climate change, unsustainable human activities, and increasing water demand. These changes have significant impacts, particularly on rural agriculture, urban migration, and socio-economic stability. A case study conducted in the Kulgad sub-watershed of the Upper Kosi River watershed in Almora, Uttarakhand, sought to address this pressing issue by identifying the importance of stakeholder engagement in springshed management. The study reveals that the decline in spring discharge can be mitigated through a collaborative approach that integrates scientific knowledge with community-driven interventions. The research emphasizes that water management is not solely a technical challenge, but also a matter of human values, behaviors, and political dynamics. Discharge of major streams were measured by using V-notch and current flow meters, while the volumetric method was adopted for the discharge calculation of springs. The river's stage was continuously monitored using an Automatic Water Level Sensor (AWLS), which was installed in a stilling well-constructed from perforated pipes. The AWLS utilized a capacitance-based water level recording system, integrated with a data logger to ensure accurate and real-time monitoring of water levels. One of the key findings of the study is the critical role of public-private partnerships (PPP) and participatory approaches in large-scale spring rejuvenation efforts. By involving various stakeholders, including local communities, government bodies, and private organizations, these approaches create a more sustainable and effective management model. Additionally, the study highlights the importance of capacity development and knowledge transfer as science of springshed management is not so simple like watershed management. This includes training local hydrogeologists, mapping recharge areas, and implementing sustainable land-use practices, which are essential for ensuring the long-term sustainability of water resources. The research underscores the need for a transdisciplinary approach to addressing the challenges of declining these community resources. By incorporating the perspectives of various stakeholders, such as policymakers, researchers, and practitioners; this approach aims to promote sustainable water management. It also aligns with the broader goals of the United Nations Sustainable Development Goals (SDGs), particularly those focused on clean water and sanitation, sustainable cities, and climate action.

The study engages the village community in water conservation, focusing on training locals in smart cash crop-based agribusiness, spring discharge calculation and rejuvenation techniques. By involving women in sustainable agriculture-based startups, the study strives to

achieve gender equity (SDG 5), empowering women to become key players in water and resource management. The study seeks to increase water availability, directly contributing to SDG 6 (Clean Water and Sanitation), and improve the community's economic, physical, and mental well-being, addressing SDG 10 (Reduced Inequalities). By involving the community in water management and sustainable practices, the study promotes responsible consumption (SDG 12). It is also supporting climate-resilient agriculture, like mulberry cultivation, contributing to carbon sequestration (carbon credit) and reducing soil loss, addressing SDG 13. The new line of action in terms of the young generation will be trained to develop young entrepreneurs in the region by linking springshed management to the local livelihood. Ultimately, this will ensure the long-term sustainability of the springs, fostering economic prosperity and community well-being. Our ultimate objective is to restore the region's diminishing water resources, a task that cannot succeed without the active involvement of local villagers. Due to limited empowerment opportunities, villagers have shown little interest in rejuvenation efforts. The region's economic development is hindered by the decreasing availability of water resources. As climate change affects rainfall patterns, rainfed agriculture is in decline, making the need for climate-resilient crops essential for agri-based socio-economic development. Therefore, the empowerment of local villagers and low-income families depends on the rejuvenation of water sources. A key crop for this project will be Mulberry, which has not been widely prioritized in the region. Mulberry leaves are rich in antioxidants, and products derived from both the fruit and leaves such as tea, extract, juice, and jam offer viable solutions for sustainable springshed management and improved livelihoods in the HKH region. In conclusion, the Kulgad case study offers a valuable framework for addressing the issue of declining spring discharge in the HKH region. By fostering a community-centric, collaborative approach and prioritizing knowledge-sharing and capacity-building, it provides a roadmap for managing the region's vital water resources in a sustainable manner.

Keywords: *Hindu Kush Himalaya, sustainable spring water management, transdisciplinary approach, hydrological investigation, social hydrology*

APPRISAL OF HYDRO-CHEMICAL REGIME FOR WATER RESOURCE CHARACTERIZATION IN SOUTHERN PART OF GAULA MICRO-WATERSHED, UTTARAKHAND, INDIA

Tanishtha Nandy[1]*, Gopal Krishan[2], Aditya Sarkar[1] and Pradipta S. Ghosh[1]

[1]*Department of Geology, Presidency University, Kolkata, West Bengal, India*
[2]*National Institute of Hydrology, Roorkee, India*
[*]*Corresponding author e-mail: tanishtha.nandy@gmail.com*

The scarcity of freshwater resources has become a harsh reality for many regions, with factors like excessive groundwater abstraction and water pollution exacerbating the issue. This has even been noticed in the upper reaches of the Himalayan region that had remained untouched by human interventions up until recently. The need for management water resources in this region is extremely critical as some of the most prominent freshwater sources originate here and therefore their deterioration would not only affect the freshwater resources in their vicinity, but also create pressure on area in downstream regions. In this view, the study tries to highlight the hydro-chemistry in the southern parts of Gaula micro-watershed, Uttarakhand. This area located at the foothills of the Kumaon Himalayas, has witnessed a drastic rise in human encroachment in recent years. The study focuses on a stretch of about 48.8 km^2 that lies between the upstream parts of Baliya River and Gaula River up until the parts of Haldwani city, located in the alluvial fan of the river system. While the river system is most primary water body in the area, it also has a variety of water sources, ranging from streams and springs that moves along hill slopes in the upstream parts to groundwater occurring in the lower reaches. This transition in natural water sources led to an appraisal of water chemistry included collection and analysis of 13 water samples from different sources (including river, streams, canal, and groundwater from both deep and shallow aquifers) at regular intervals to evaluate their spatial and seasonal variability and vulnerability to contamination using water quality indices. It also included remote sensing-based assessment of the area to review land use changes as well as morphometric characterization of the watershed. Some of the primary observations from the pre monsoon phase of this work revealed some significant inferences to delineate water sources based on their source as well as chemical features.

The pH value of all the water samples range between 7.39 to 8.6 averaging 8.04 indicating slightly alkaline conditions, while EC values range from 28.13 to 1203.13 µS/cm, averaging 453.33 µS/cm. Notably, the Nitrate concentrations, which is common indicator of anthropogenic influences, was confined to water samples from shallow aquifers and ranges from 19.41 to 175.48 mg/L, averaging 38.978 mg/L, among which 2 water samples showed values which was beyond the WHO standards. In addition, the water samples were also viewed for hydrochemical facies variation which highlighted the prominence of Ca-HCO_3 type in all samples. However, when viewed as per the different sources, there was a clear distinction between facies for groundwater and surface water sources. The Ca-HCO_3 type water in the stream and Gaula River system could be distinguished from Na-HCO_3 types facies in shallow aquifer samples in transition area. Similarly, inferences from the Durov Plot showed the when facies were further delineated with respect to EC, majority of the water samples, including from river and springs, remained below 300 µS/cm, with only exception being the handpumps (shallow aquifer) samples. Further, evaluation of hydrochemical character of was conducted using other tools such as the Richard's plot for irrigational

suitability and weighted arithmetic water quality index (WAWQI) for vulnerability to contamination. According to Richard's Plot, 25% of the surface water belongs to C2-S2 category, 25% of the surface water belong to C1-S1 category and 50% of the surface water belongs to C2-S1 category. The 50% spring water belongs to C2-S1 category and remaining 50% belongs to C1-S1 category. The 33% of groundwater belong to C2-S1 category, 33% of the groundwater belong to C2-S2 category, 16% groundwater to C3-S1 category and remaining 16% belong to C3-S4 category. The result revealed that surface and springs water are ideal for irrigation purpose while groundwater needs to be treated properly before using for irrigation purpose. Similarly, the WAWQI used in the study showed highly variable values for all water samples ranging from 34.55 to 341.19. However, when observed for separate sources, the average WAWQI values of groundwater was much higher than that of surface water and springs.

The extensive hydrochemical characterization of this area was further explored for both spatial and seasonal variation. While the post monsoon phase of the water quality assessment added a few more insights into the characterization, it was the spatial aspect of the study that gave some critical inferences. The morphometric analysis highlighted the high stream order and distribution of streams and springs, while the land use pattern supported the notion of anthropogenic influence limiting to the lower reaches of the area. It could be proposed that the although the area has been isolated from human activity, the growing development in lower reaches and the disruption of surface water sources have strong effect on water quality. Furthermore, the different sources of water in the area have strong geomorphic control, which seems to be weaning for more urbanized lower reaches of the study area.

Keywords: *Hydro-geochemistry, Gaula micro-watershed, water quality indices, land use pattern, morphometric analysis*

HYDROLOGICAL VULNERABILITY AND DISTRIBUTION OF SPRINGS IN THE LIDDER WATERSHED, KASHMIR HIMALAYA, INDIA

Faisal Abass Padder[1*], R.S. Kumar[1], Riyaz Ahmad Mir[2] and Kainat Aziz[3]

[1]*Department of Earth Sciences, Annamalai University, Chidambaram, Tamil Nadu, India*
[2]*Western Himalayan Regional Centre Jammu, National Institute of Hydrology, India*
[3]*Centre for Sustainable Water Research, Indian Institute of Technology, Guwahati, India*
[*]*Corresponding author e-mail: faisalabas049@gmail.com*

The Lidder Watershed located in the Kashmir Himalaya, is a vital region for both the local ecosystem and human populations, primarily due to the essential role that springs play in providing water resources. This study examines the spatial distribution and hydrological status of springs within the watershed. Its primary focus is to explore the causes behind spring desiccation and the factors contributing to the growing vulnerability of these water sources. In the Lidder Watershed, springs are crucial to the local hydrological cycle, supporting water supplies, agriculture, and biodiversity. However, recent observations have shown a troubling decline in the discharge of these springs, indicating a potential hydrological crisis. Through field surveys and the analysis of geospatial data, this research maps 82 springs across varying altitudes, geological conditions, and land-use types. Springs are primarily located between 1500 and 1800 m above mean sea level, with a higher concentration near urban areas. Geologically, these springs are situated in areas conducive to groundwater storage and discharge, such as regions with alluvial deposits and Triassic limestone, which exhibit high porosity and permeability. These geological conditions facilitate groundwater flow and storage, supporting the sustained discharge of springs. In contrast, areas with less permeable formations show a lower density or absence of springs, highlighting the critical role of geology in the availability and sustainability of spring water. Despite the relatively high density of springs in certain areas, the study reveals an alarming trend: seven springs have completely dried up, signalling a concerning decline in the watershed's hydrological stability. The drying of these springs indicates an increasing hydrological vulnerability, influenced by both natural and anthropogenic factors.

This study identifies land-use changes, rapid urbanization, and ongoing climate change as the primary drivers of spring desiccation in the catchment. The analysis of the spatial distribution of drying springs reveals a strong correlation with areas undergoing land use changes and rapid urbanization. Urban sprawl significantly reduces the recharge capacity of local aquifers. The conversion of natural landscapes into urban environments, characterized by impervious surfaces like concrete and asphalt, disrupts the natural water infiltration processes. As a result, groundwater recharge is severely limited in urbanized areas, preventing the replenishment of aquifers that supply spring water. Consequently, the groundwater table does not recover quickly enough to sustain spring flow, leading to the drying of previously reliable water sources. Alongside urbanization, climate change is increasingly influencing the region’s hydrological patterns. Shifts in temperature, precipitation, and snowmelt dynamics are having a profound impact on local water resources. Altered precipitation patterns, such as reduced snowfall and irregular rainfall events, coupled with changes in snowmelt timing, disrupt the region's natural water balance. Warmer temperatures lead to earlier snowmelt, reducing the water available for groundwater recharge during crucial months. Moreover, erratic rainfall patterns and increased evaporation due to higher temperatures exacerbate challenges in maintaining sufficient groundwater levels. These disruptions are likely to increase the vulnerability of springs, as the natural recharge processes essential for sustaining these water sources are increasingly interrupted.

The consequences of spring desiccation in the Lidder Watershed are far-reaching, impacting both local communities and surrounding ecosystems. Springs are a critical water source for many rural areas where piped water access is limited. The loss of spring water would significantly affect agriculture, drinking water supplies, and daily life. Additionally, springs are vital for maintaining riparian ecosystems, wetlands, and local biodiversity. The depletion of spring water could lead to the collapse of these sensitive ecosystems, further intensifying the environmental impacts of spring drying. This study provides essential baseline data for managing and conserving water resources in the Lidder Watershed. The findings highlight the need for a comprehensive understanding of the factors influencing spring sustainability, including geological conditions, land-use practices, and climate change. Effective management strategies must account for the complex interplay between these factors. Urban development should be carefully managed to minimize disruption to natural recharge areas, and land-use policies should prioritize the preservation of groundwater recharge zones. Furthermore, water resource management must incorporate climate change projections to address future shifts in precipitation patterns, temperature, and snowmelt timing. To mitigate spring drying in the watershed, adaptive strategies should focus on restoring aquifers, constructing recharge structures, and promoting water conservation. Sustainable urban planning, such as reducing impervious surfaces and utilizing green infrastructure like permeable pavements and rainwater harvesting, can help support groundwater replenishment. Regular monitoring of climate and hydrological variables is essential to adapting to future changes in water availability. This study underscores the region's growing hydrological vulnerability and the need for integrated water resource management that considers geological, anthropogenic, and climatic factors, ensuring the long-term sustainability of spring water for local communities and ecosystems.

Keywords: *Springs, vulnerability, climate change, Lidder watershed, Kashmir Kimalaya*

INVESTIGATION OF GROUNDWATER RECHARGE ZONES IN THE UPPER GANGA BASIN, INDIA

Nikitasha Chatterjee* and Anil K. Gupta

Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India
**Corresponding author e-mail: chatterjeenik001@gmail.com*

The groundwater has immense importance in sustaining high-altitude streams during the dry season. Previous studies on groundwater age tracers inferred that shorter groundwater flows having low residence times supply streams and springs at higher elevations, while longer, geochemically mature groundwater flows are sources for streams at lower elevations. Though flatter alluvial terrains are appropriate for groundwater storage but crystalline fracture networks in the mountainous regions can also serve as good aquifers. In shorter groundwater flows, recharge is directly correlated with discharge, whereas longer flows retain recharge for extended periods and are more sensitive to recharge rates. Also, snow-melt pulses contribute more to runoff, inter-flow and soil water whereas, groundwater fraction increases as the pulse is reduced. This creates an importance of researching on the groundwater potential of the Himalayan rivers, particularly how it is vulnerable to recharge rates. In the Himalayan watersheds, streamflow is sustained by snow/glacier melt during the ablation season (May-June), rainfall during the Indian Summer Monsoon (ISM) (July - September), and groundwater during the dry months (December-March). The Main Central Thrust (MCT) zone in the Higher Himalaya is known to be the source of numerous springs, but how it functions as a recharge-discharge zone in the Upper Ganga Basin (UGB) on an annual basis remains unclear.

This study aims to investigate the recharge-discharge zones in the two Himalayan watersheds in the UGB in India using satellite reanalysis data. Our study encompasses the Bhagirathi and Alakananda Basins which are two pristine watersheds in Uttarakhand, India. Originating from glaciers in the Higher Himalaya, these two rivers form sources of the extensive River Ganga, which sustains the livelihoods of nearly half of India's population. In their upper courses, the rivers drain over the Higher Himalayan Crystalline rocks, comprising high-grade meta-sedimentary schists and gneisses. These rivers then cross the MCT zone at elevations of 1000 to 1500 m above mean sea level (amsl) before flowing over the low-grade Lesser Himalayan sandstones, quartzites, and carbonates. The two basins receive an annual average rainfall of 1000 to 2000 mm, with precipitation occurring primarily as ISM rainfall from July to September and as snowfall spells from October to March. For this study, we used hourly data on surface runoff, subsurface runoff, and volumetric soil water layer (VSWL) from 2019 to 2023, across 14 locations in the Bhagirathi Basin and 12 locations in the Alaknanda Basin, covering elevations from 500 to 3000 m amsl. This data was sourced from the ERA5 reanalysis data provided by the Copernicus Climate Change Services at the European Centre for Medium-Range Weather Forecasts (ECMWF). We aggregated the hourly data to a daily scale and calculated an average value for each month, which we refer to as the monthly average data.

The monthly average surface runoff increases by 8-9 times in the peak ablation month (June) and by 5-6 times during the ISM period compared to other months in the Bhagirathi Basin. In the Alaknanda Basin, ISM surface runoff increases by almost 12 times in August, however, no peak is observed in June. Further, June runoff peaks occur between 1500 and 3000 m amsl, while ISM runoff peak is observed between 1000 and 1500 m amsl. The monthly average sub-surface runoff also shows 5-7 times increase during the late ISM (August and September) between 1000 and 1500 m amsl elevation, but no significant increase is seen during the ablation period. The region between 1000 and 1500 m amsl altitude is the MCT zone which is a broad zone of brecciated metasedimentary rocks characterized by faults and fracture networks. The soil-water content also increases with depth in this zone as observed from the VSWL data. The monthly variations of surface, sub-surface, and VSWL are persistent across the years 2019-2023. The annual runoff and VSWL variations in the basins suggest that the MCT zone between 1000 and 1500 m amsl altitude acts as an active recharge–discharge zone in the Bhagirathi and Alaknanda Basins. The snow/glacier melt during the peak melting season (May-June) from higher altitudes percolates within the fractures of the MCT and recharges the carbonate aquifer system of the Lesser Himalaya below 1000 m amsl. Similarly, recharge occurs again during the late ISM (August - September) as indicated by the sub-surface runoff trends. In the early ISM season (July), the stored ablation water along with the rainfall drains over the terrain, and only after sufficient rainfall, the fracture-aquifers of the MCT get recharged. This late ISM recharge emerges as springs and seeps in the valley during the post-monsoon month of October. Our study highlights the importance of the Himalayan thrust zones as potential groundwater recharge zones. The fracture networks of the MCT zone between 1000 and 1500 m amsl in the Bhagirathi and Alaknanda Basins store glacial meltwater and late monsoon rainwater, which sustain the rivers during the dry months at lower altitudes. Further studies could focus specifically on the sensitivity of Himalayan groundwater to climate change.

Keywords: *Upper Ganga Basin, Himalayan aquifer, groundwater recharge, main central thrust, fracture networks*

SPRINGSHED MANAGEMENT IN THE LESSER HIMALAYAS USING A GEOHYDROLOGICAL, GEOSPATIAL AND GEOPHYSICAL TECHNIQUE

Praveen Kumar, Pallavi Chattopadhyay* and Ravi Shankar Dubey

[1]Department of Earth Sciences, Indian Institute of Technology, Roorkee, India
**Corresponding author e-mail: cpallavi@es.iitr.ac.in*

Springs are vital sources of drinking water for mountain communities worldwide. These communities rely heavily on accessible springs for agricultural, household, and economic needs. Beyond domestic and commercial uses, springs also provide the essential base flow for rivers during dry periods. Despite their critical importance, Himalayan springs have been under increasing natural and human pressures, leading to a decline in their discharge over recent decades. Natural factors, such as fewer rainy days and shifts in rainfall patterns, along with human activities like vegetation loss, urban expansion, and the construction of roads and tunnels, are significant contributors to spring depletion. This research aims to conduct a comprehensive analysis of the hydrological factors influencing spring emergence and distribution by developing an integrated approach for effective springshed management in the Kalsi region of Uttarakhand, located in the Lesser Himalayas. Studying the hydrological control factors and recharge structures in accordance with the geological characteristics of the Himalayan region could help rejuvenate these diminishing springs. Springs play an indispensable role in supporting the livelihoods and ecosystems of mountain communities worldwide, providing a primary source of drinking water and serving essential agricultural, household, and economic functions. This study emphasizes the critical assessment of spring occurrence (GWSPZ) and its hydrological drivers as an important concern for institutions responsible for water resource management, regional land use planning, and environmental conservation. This research seeks to improve the understanding of spring hydrology in the Himalayan region.

The study delineates groundwater potential mapping and spring sustainability evaluations by utilizing a combination of GIS-based multi-criteria decision analysis (MCDA) through the Analytic Hierarchy Process (AHP) and geophysical Electrical Resistivity Tomography (ERT) surveys. Numerous factors, directly and indirectly, affect the behavior of springs. So, the methodology involves the selection and analysis of thematic layers controlling the spring emergence based on the literature survey and advice of hydrological experts such as lineament density, slope, lithology, geomorphology, drainage density, rainfall, soil, Aspect, LULC and Normalised Difference Vegetation Index (NDVI). The geology and geomorphological layers were downloaded from the Bhukosh portal. The Digital Elevation Model (DEM) was downloaded from ALOS PALSAR data with a resolution of 12.5 m. The LULC map was created by training the Landsat 8 satellite image samples in a GIS environment using the Support Vector Machine algorithm in ArcGIS software. The vegetation index NDVI was calculated for the Landsat 8 image using the raster calculator in ArcGIS. All the thematic layers were analyzed in a GIS environment with the same resolution. A pairwise comparison matrix was created by allocating weights to various parameters using the AHP methodology. Following the allocation of weights to each parameter and its sub-parameters based on their significance in Spring hydrology, a spring potential map is generated by superimposing and integrating all layers on a pixel basis using a weighted overlay approach inside the ArcGIS environment. This methodology is validated with field-based data, including spring locations and ERT pseudo-sections, ensuring robustness and reliability. The study used location data of 180 springs collected from the field to validate groundwater potential maps. The relationship between the different thematic layers and the groundwater potential values presents the relative importance of different hydrologic layers in controlling the emergence of springs. A hydrogeological field survey was also conducted to assess the geological conditions that lead to the formation of groundwater pathways channeling toward the spring flow.

The study region is categorized into five distinct groundwater spring potential zones: very low (0.1%), low (5.4%), moderate (39.01%), high (50.7%), and very high (4.75%). Approximately 93% of the research region is classified within the "moderate" to "very good" potential zones. The Receiver Operating Characteristic (ROC) curve indicates that the area under the curve (AUC) was 85%. The 2-D electrical resistivity tomography (ERT) measurements conducted at five sites underscore the significance of shallow preferential and saturated zones in channelizing springs. The findings also highlight the strong correlation between geological structures like fractures, faults, etc., identified by geospatial, hydrogeological survey, geophysical resistivity method, and spring emergence. This study seeks to address this pressing issue by analyzing the hydrological factors that influence spring emergence and distribution. The results demonstrate the efficacy of integrating GIS with geophysical methods to create more precise and comprehensive groundwater potential maps. Through an integrated approach to springshed management in the Kalsi region of Uttarakhand in the Lesser Himalayas, study identified strategies that align recharge structures with the region's unique geological characteristics, ultimately contributing to the rejuvenation of the region's declining springs. This study provides valuable insights for planners and policymakers to develop targeted, region-specific recharge structures and management strategies. The proposed framework contributes to the sustainable management of springsheds, improving water security and resilience for local communities facing climate and human-induced water stress. Future study should focus on more geophysical surveys to understand different types of geological conditions which are governing the springs.

Keywords: *Spring, Himalaya, GIS, AHP, ERT, rejuvenation*

EVALUATING MULTIPLE DATASETS FOR MODELLING SNOW-GLACIER MELT RUNOFF DYNAMICS IN BHILANGANA BASIN, INDIA

Bhupendra Joshi[1*], Vishal Singh[2] and V.K. Chandola[1]

[1]Banaras Hindu University, Varanasi, India
[2]National Institute of Hydrology, Roorkee, India
[*]Corresponding author e-mail: bhupendra.bhu@bhu.ac.in

The Himalayas are home to an extensive network of glaciers, which act as significant freshwater reservoirs feeding major river systems. These play a crucial role in shaping the hydrology and climate of any region. These glaciers are essential for sustaining hydrological processes, agricultural productivity, and ecological balance. However, in recent decades, accelerated glacier melting due to climate change has raised serious concerns about long-term water availability and the stability of hydrological systems. This study evaluates the impacts of climate-induced snow and glacier melt runoff on the total discharge of the Bhilangana River Basin, a significant tributary of the Bhagirathi River in Uttarakhand, India. The study area is located in the Garhwal Himalayas of the state and the total area of basin is around 1500 km^2. One of the major Glacier presents in the basin is Khatling glacier, whose terminus is the source of origin of the Bhilangana River. Being dependent for its discharge, primarily on glaciers, future climate change projections and impacts make this river more vulnerable. The Spatial Processes in Hydrology (SPHY) model was employed to simulate the hydrological processes governing snow and glacier melt runoff in the basin. SPHY model is well known for its capabilities to simulate the snow-glacier induced melt runoff dynamics particularly for Himalayan areas. To set up the model, sensitivity analysis was carried out to identify critical model parameters and their influence on discharge simulation, enhancing the model's calibration and validation accuracy. Parameterization is one of the pre-requisite steps to allow the model to simulate the various scenarios based on the data and other climatic conditions. Available precipitation and temperature global gridded satellite products such as ERA5 (0.25 x 0.25^{o} resolution), IMDAA (0.125 x 0.125^{o} resolution), IMD (0.25 x 0.25^{o} resolution for precipitation and 1 x 1^{o} resolution), and APHRODITE (0.25 x 0.25^{o} resolution), were downloaded for the study area and used comprehensively to analyze snow glacier melt dynamics for the period 2020-2023. Data for the model setup period (i.e. precipitation, average temperature, minimum temperature and maximum temperature) were extracted from the downloaded nc files into csv files using the python script. Widely used RGI 7.0 inventory was used to delineate the glaciers present in the basin. Statistical evaluation of the model results was done using the Nash–Sutcliffe efficiency (NSE), Coefficient of determination (R^2), and mean bias between the observed and simulated dataset.

The model results showed that the utilized satellite products, known for their high temporal and spatial resolution, effectively captured variations on total discharge generation which is the sum of snow q, base q, glacier q and rain q. The performance matrix revealed that the ERA5 dataset performed better than other datasets with an R^2 of approximately 0.74, NSE of 0.72, and a bias of -4m^3/s on a daily time scale. These values suggest that the ERA5 dataset reliably captures the hydrological dynamics of the basin, with minimal deviation from observed data. The relatively high R^2 and NSE values highlight the model's accuracy in simulating snow and glacier melt processes, while the bias of -4 indicates a slight underestimation of runoff in the model. Subsequently, scatter plots showed a strong agreement between the observed and modeled runoff values. The average variation during

2000-2023 in snow q was found in the range of 12 to 25%, rain q from 10 to 60%, glacier q from 60 to 20% and base q from 10 to 20 %, respectively while moving from selected high elevation points to low elevation points inside the basin. The analysis further revealed that 11 parameters were found to be critical in influencing the model's output e.g. Degree Day factor for snow (DDFS), Glacier debris degree day factor (DDFG), Tcritical, Glacier melt frac runoff. Degree day factor for snow and glaciers are crucial parameters which should be finalized combing the literature values with the hit and trail approach. Also, critical temperature needs to be adjusted based on the local conditions, and practically can vary from zero degrees in most of the cases. The study also suggest that the debris cover should be properly delineated to account for change in glacier melt fraction runoff.

The study finding reinforces the suitability of satellite gridded datasets in absence of station rainfall data of the area. The applicability of ERA5 dataset is well reinforced for hydrological modeling in glaciated basins like Bhilangana, for providing a reliable basis for future predictions. However, continuous monitoring and refinement may be necessary to further reduce model biases and improve the accuracy of runoff projections under changing climatic conditions. By focusing on the critical parameters, analysis can better provide a deeper understanding of the system's sensitivity, facilitating better decision-making in glaciated basins. Furthermore, this research underscores the suitability of the SPHY model for analyzing snow-glacier melt runoff dynamics and the importance of integrating multiple climate datasets to accurately predict the water resource scenarios in glaciated basins.

Keywords: *Bhilangana, glaciers, SPHY, degree day factor, ERA5*

MAPPING AND MANAGING OF SPRINGSHED FOR WATER CONSERVATION USING GEOSPATIAL TECHNOLOGY IN KALIMPONG DISTRICT OF DARJEELING HIMALAYA, INDIA

Abhijit Sen[1*] and Tapan Kumar Das[2]

[1]Cooch Behar Panchanan Barma University, West Bengal, India
[2]Cooch Behar College, West Bengal, India
[*]Corresponding author e-mail: abhijitsengeo@gmail.com

Spring is a natural discharge point of groundwater system. Many of India's rivers, both large and small are formed from springs. More than 15% of the populations of India rely on natural springs for all or part of their water needs. In the mountainous districts of the Indian Himalaya Region (IHR), millions of people and their livestock depend on springs as their main source of water. Spring water is an essential life sustaining resource to the people living both in rural and urban areas of IHR for their agricultural, domestic and drinking purposes. The groundwater movement, which is usually discharged as spring water, is influenced by the underlying geology, lineament and the characteristics and slope of the rock's beds located below the surface. Springshed of a particular spring is an area of recharge to discharge point of spring including aquifer and its movement. The complex geology of the Himalayan region, characterized by folds and fault structures, often reshapes springsheds. The conservation of springsheds involves protecting the IHR ecosystem that feeds the spring water supply from the land surface to the groundwater. Effective springshed conservation techniques often include the factor of land use practices in the IHR agriculture production Roots from trees, grasses, and shrubs improve soil structure and allow for better infiltration of water into the ground. Long-term spring flow in the springshed depends on sustainable water use. Regular monitoring of the spring's water quality and quantity, together with changes in the surrounding land use, can help identify possible issues early. Integrating geospatial technology and hydrological modeling techniques, this study attempts to delineate the springshed and spring water conservation.

The study area covers entire Kalimpong district situated at an average altitude of 1250 m above mean sea level (amsl) on the eastern part of Darjeeling Himalayas of West Bengal splitting from the Darjeeling district. The district of Kalimpong is one of the northern districts under the jurisdiction of West Bengal lying on the lesser Shivalik Himalayas. The drying of springs during the lean season has led to acute water shortages and great distress to the people of Kalimpong District along with their livestock. A conceptual hydro-geological layout is developed which serves as the basis for identifying the springshed (recharge zone, aquifer, flow direction and discharge point). Springshed mapping are done using Remote Sensing (RS), GIS and Global Nevigation Satelite System (GNSS) with a field survey identifing the rock type and structures around the springs and other factors. The main factors considered in the present study, which are influential to the occurrence of a Spring Recharge Zone (SRZ), are Rainfall, Slope, Geology, Lineament, LULC, NDVI, Soil (Hydrological Group), and Land Gravity. The spring discharge points are then identified using field survey by handheld GPS and secondary data. A vector-type spatial database has been obtained by transforming raster to vector format using the digital elevation model (DEM) for deliniationg spring recharge zone by overlay analysis, which represents the quantitative relationship between spring occurrence and different causative parameters as there is a perfect linear relationship exists among them. The Landsat and SRTM DEM (30 m) data have been

collected from USGS earth explorer whereas Soil HSG map from NASA EATHDATA, rainfall data from IMD, Geomorphology, Geology and Land Gravity data from Geological Survey of India, Spring location and typology data have been collected from CGWB. The rock's strength is determined by its geological structure. There are two geological layers in the Kalimpong district: undivided Paleozoic rock and undivided Precambrian rock. The maximum elevation of the Kalimpong area ranges from 660 m to 3124 m amsl. Very high maximum relief is found in a small portion of northern Kalimpong, high maximum relief is found in the northeastern part of Kalimpong and very low maximum relief is found in a small southern area of Kalimpong. These geological beds make up 40.70% and 59.30% of the study area, respectively. The northern middle section of Kalimpong contains undivided Paleozoic rock, whereas the remaining portion is covered with undivided Precambrian rock. Finally, the springsheds are created using the various thematic maps and field-based expertise and knowledge.

The investigation has revealed that the type of spring sources are Fault springs, Fracture springs, Perennial springs, and Seasonal springs which are collectively contributing to the needs water of the local population and feed the river. The results indicate that the predominant land-use type in the Kalimpong-I and Gorubathan blocks are settement and agricultural, whereas in the Kalimpong-II block is the main land cover type consist of forest and farmlands. Conceptual framework of the springshed has been developed and the different types of springs were categorized indentifying the boundary of springshed. The outcome of this research work is expected to make a strong foundation for springshed delineation and used for water conservation in future. Proper spring water management is necessary for the development of rejuvenating springs in order to sustain soil fertility by preventing soil and water erosion and promoting horticulture. The conservation technique and management strategies of springsheds help with ensuring the sustainability of natural water resources for agriculture, ecosystems, and people. This makes it possible to employ timely interventions and flexible management techniques, such as changing land use type or replanting plants. For springshed conservation initiatives to be successful in the future, local residents must be involved. Better practices at the individual, community, and governmental levels may result from this study on the value of springs and strategies for their protection.

Keywords: *Spring water, springshed, spring recharge zone, hydro-geology and geospatial techniques, Indian Himalayan region*

INVESTIGATING THE GEOCHEMICAL CHARACTERISTICS OF SPRINGS AND GROUNDWATER POTENTIAL IN ASSAM HILLS FOR SUSTAINABLE SPRINGSHED MANAGEMENT

Mayurakshi Gogoi* and Runti Choudhury

Department of Geological Sciences, Gauhati University, Guwahati, India
**Corresponding author e-mail: mayurigogoi5252@gmail.com*

Springs are vital water sources for millions residing in hilly and mountainous regions. Factors influencing spring discharge include underground rock cavities, aquifer pressure, basin area, rainfall, and human activities like groundwater extraction. It has been reported by previous researches that India's springs are facing water scarcity due to groundwater overuse with increasing population growth and climate change. Recommended strategies for effective springshed management include hydrogeological mapping, discharge monitoring, water quality assessment, and recharge modeling, etc. Studies show that springs can be contaminated by waste disposal, agricultural runoff, and other human activities. Thus, monitoring physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), major anions (HCO_3^{-}, Cl^{-}, NO_3^{-}, PO_4^{3-}, SO_4^{2-}), and microbial contaminants is essential for evaluating spring water quality. Certain regions like Assam, where spring water is presumed pure, have seen less focus on water quality. This study explores both the hydrogeological settings and water quality of springs in the hills of Assam's Dima Hasao district, where these parameters are not well documented. During the dry season of January 2024, 46 spring locations were examined. GPS coordinates, slope, rock types, and land use data were collected, along with discharge rates measured by recording the time taken to fill a container. The springs, found in fracture zones joint planes, and contact zones between residual soil and bedrock with varying elevations. Discharge rates ranged between 0 to 12 liter/minute (lpm) with a mean discharge of 2.38 lpm. All are non-thermal springs, with temperatures less than 37°C. They can also be categorized as fracture/joint springs and depression springs based on geology. As per Meinzer's classification, springs are ranked as sixth, seventh and eighth magnitude. Field water quality testing kit was used to measure pH, TDS, EC, and temperature. Major cations and anions, Fe were analyzed following the standard procedures of APHA using flame photometer, spectrophotometer, volumetric titration methods as required. All the parameters were within acceptable values of WHO and BIS Standards. Water types identified included Ca-Mg-Cl-SO_4, mixed Ca-Mg-Cl, and Ca-Mg-HCO_3, indicating mixed temporary and permanent hardness. Precipitation is found as the primary factor controlling the water chemistry. The off-axis integrated cavity output spectroscopy method was used to determine the $\delta^{18}O$ and $\delta^{2}H$ concentrations in the Liquid-Triple Isotopic Water Analyzer (L-TIWA). The analysis of stable hydrogen and oxygen isotope indicated the contribution of recycled moisture to local precipitation with a few secondary evaporative effects. The Water Quality Index was calculated for drinking water suitability based on basic chemical parameters. For irrigation, indices like Sodium Adsorption Ratio, Sodium Percentage, Residual Sodium Carbonate, and Permeability Index were used.

Water Quality Indices from chemical parameters showed that most springs had excellent to good water quality for drinking. All springs are suitable for irrigation as per irrigation indices. Most Probable Number (MPN) determination by following APHA. Findings from bacterial analysis showed significant faecal contamination in all springs. Thematic layers including slope, drainage density, lineament density, land use land cover, geomorphology, and lithology were generated using remote sensing and GIS techniques to delineate Groundwater Potential Zones (GPZs). Analytical Hierarchy Process was used for factor weighting, the consistency Index and consistency Ratio verified the accuracy of these weights for GPZ mapping. Weighted overlay analysis was conducted in ArcGIS 10.8.2 software. GPZ mapping revealed that 58.20% of the total area had moderate groundwater potential, while 26.65%, 13.04%, 2.09%, and 0.03% had high potential, poor potential, very high potential, and very poor potential respectively. The occurrence of springs in the area is compared with the GPZs and results have shown that the occurrence of sixth, seventh and eighth magnitude springs was located in predicted very high, high, moderate, and poor potential zone areas. The findings from this study were crucial for springshed management, indicating areas where artificial recharge structures may benefit spring discharge. Although the quality is good for drinking and agricultural purposes based on chemical parameters, adequate treatment of spring water is essential because of the microbial contamination. Considering seasonal variations in spring water discharge and quality, mapping groundwater and groundwater springs potential zones, constructing artificial recharge structures can contribute to effective water management in the hills of Dima Hasao and similar regions facing climate impacts. The study highlights the importance of regularly monitoring spring resources in Dima Hasao hills, artificial recharge to maintain spring discharge amidst climate change, aiding policymakers in crafting sustainable management plans to meet the UN's sustainable development goals XIII (climate change action).

Keywords: *Spring, groundwater, groundwater potential, springshed management, water quality indices*

SPRINGS WATER QUALITY EVALUATION USING WATER QUALITY INDEX AND GEOSPATIAL TECHNIQUES IN BHILANGANA BLOCK OF TEHRI GARHWAL DISTRICT, UTTARAKHAND, INDIA

Siddharth Rana[1*], Gaurav[2] and M.S. Panwar[1]

[1]Department of Geography, School of Earth Sciences, Hemvati Nandan Bahuguna Garhwal University, Srinagar Garhwal, Uttarakhand, India
[2]Department of Geography, Indraprastha College for Women, University of Delhi, New Delhi, India
[*]Corresponding author e-mail: siddharthrana617@gmail.com

As natural sources of groundwater, springs have long been vital to human communities, particularly in mountainous and rural regions, offering a reliable and sustainable water supply. These water sources typically emerge from an aquifer, creating a visible flow on the Earth's surface. They are highly regarded for providing relatively pure water compared to other bodies such as rivers and lakes. In regions like the Indian Himalayan Region (IHR), the Western Ghats, the Eastern Ghats, and the Satpura and Vindhya Mountain ranges, spring water is essential for the survival of over 200 million people. In these areas, springs not only serve as a crucial drinking water source but also have cultural significance and serve agricultural and domestic needs. In particular, the Bhilangana block in the Tehri Garhwal district of Uttarakhand has a long-standing tradition of depending on springs for drinking water. Springs are often considered one of the most sustainable and reliable sources of groundwater due to their natural replenishment and relatively fresh water. However, spring water quality can vary significantly due to various factors, including the composition of the aquifer materials, local environmental conditions, and human interventions such as deforestation, urbanization, and contamination from agricultural runoff or sewage. Therefore, ensuring the safety of spring water for human consumption becomes critical, especially in the context of changing climate patterns, increased population pressures, and the potential deterioration of water quality over time. The Bhilangana block, located in the mountainous region of Uttarakhand, exemplifies these challenges, with spring water being the primary source for drinking and domestic use. This study aimed to assess the suitability of natural spring water for human consumption in the Bhilangana block of Tehri Garhwal district, focusing on the water quality of springs in Silyara, Holta, and Devlang villages.

Springs water samples were collected post-monsoon season when water quality is most susceptible to seasonal variations due to rainfall patterns and runoff changes. The study analyzed several key water quality parameters: temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), hardness, alkalinity, chloride, calcium, and magnesium. These parameters are crucial for understanding the chemical composition of spring water and assessing its safety for drinking. The results revealed notable differences in the water quality among the three springs, with varying concentrations of dissolved minerals that affect the water's taste and safety. For instance, the spring in Silyara village exhibited higher concentrations of EC (140 µS/cm), TDS (120 ppm), hardness (126 mg/L), calcium (34.4 mg/L), and alkalinity (120 mg/L), suggesting that the water had a higher mineral content. While this may impart a stronger taste to the water, the concentrations of these minerals remained within acceptable limits, making the water suitable for consumption. By contrast, the spring water from Holta village displayed moderate mineral content, with lower levels of hardness (42 mg/L) and alkalinity (32 mg/L). This made the water softer and palatable, likely appealing to people who prefer water with a lighter taste. In contrast, the water from the spring in Devlang village contained the lowest levels of dissolved minerals with values of 40 ppm for TDS, 24.0 mg/L for hardness, 6.4 mg/L for calcium, and 22.0 mg/L for alkalinity, making it the softest of the three. While the water from Devlang village is ideal for individuals who prefer low-mineral water, it may lack the characteristic taste associated with water that contains higher mineral content.

The study applied the Weighted Arithmetic Water Quality Index (WAWQI) method, a commonly used approach combining multiple water quality parameters into a single value, to understand overall water quality. The WAWQI assigns weights to different parameters based on their relative importance in determining drinking water safety. Using this method, the study classified the water from all three springs as falling within the 'Good' quality category, indicating that the water is safe for consumption and does not pose significant health risks based on the analyzed parameters. In addition to the water quality analysis, the study incorporated GIS techniques to understand the spatial distribution of water quality parameters across the study area. The Inverse Distance Weighted (IDW) interpolation method was employed to create spatial maps that visualize the distribution of temperature, pH, EC, TDS, hardness, alkalinity, calcium and magnesium for each spring. The study results provided valuable insights into the spatial variability of water quality. It helped identify potential areas of concern, such as regions where water quality may be slightly more compromised due to local environmental factors or human activities. By visualizing the data in spatial terms, the study enabled a more comprehensive understanding of the geographic patterns in water quality across the Bhilangana block, which could inform targeted water management practices. The findings of this study highlight the overall good quality of spring water in the Bhilangana block and suggest that it remains a viable and safe source of drinking water for local communities. However, the study also emphasizes the need for ongoing monitoring and sustainable management of these water resources to ensure their long-term viability. The combination of water quality indices and GIS-based spatial analysis provides a robust framework for assessing water quality in natural springs, offering valuable information for local authorities and communities engaged in water resource management. Furthermore, the results of this study can inform future strategies aimed at safeguarding the quality of spring water, addressing potential risks, and ensuring that these vital water sources continue to support the health and well-being of the dependent populace.

Keywords: *Drinking water, natural springs, GIS interpolation, spatial distribution, water quality index*

MODELLING STREAMFLOW DYNAMICS AND CLIMATE SENSITIVITY IN THE GANGOTRI GLACIER WATERSHED

Lavkush Patel, Madhusudan Thapliyal* and Surjeet Singh

National Institute of Hydrology Roorkee, India
**Corresponding author e-mail: lavkush.nihr@gov.in*

Glaciated watersheds are highly sensitive to climate change, with streamflow dynamics influenced by multiple factors such as glacier melt, snowmelt, rainfall, and temperature. Effective water resource management in these regions requires an understanding of the complex interactions between climate factors and hydrological processes. This study models the streamflow of the Gangotri Glacier Watershed, located in the Central Himalayas, which covers an area of 548 km^2, of which 48.4% is glacierized. The watershed is particularly important due to its contribution to downstream river discharge, which serves as a crucial water resource for the region. To model the hydrological processes of the watershed, the SPHY (Spatial Process in Hydrology) model was employed, which is capable of simulating the dynamics of water fluxes in glacierized regions. The climate forcing data, derived from NASA's Prediction of Worldwide Energy Resources (POWER) dataset were used. Due to potential biases in the climate data, temperature and rainfall data was corrected using observed meteorological records from Bhojwasa weather stations. Specifically, temperature data was bias-corrected using an additive scaling method, while rainfall data was corrected with a multiplicative linear scaling approach. This bias correction ensures that the model's inputs are more representative of the local climate conditions, allowing for more accurate simulation results.

A sensitivity analysis was conducted to understand the influence of various model parameters on the simulated streamflow. Sixteen parameters including the degree-day factor (DDF), recession coefficient (kx) and other parameters governing snow and ice melt were tested for their sensitivity. The analysis revealed that the DDF, which controls the rate of glacier melt, and the recession coefficient (kx), which governs the rate of flow recession during the dry season, were the most influential parameters affecting discharge predictions. This highlights the critical importance of accurately determining these parameters, particularly in glacierized catchments, where melt processes are key drivers of streamflow. For model calibration, observed discharge data from 2017 to 2019 were used. The model was calibrated by adjusting the key parameters until simulated streamflow closely matched the observed discharge values. The model was then validated using discharge data from 2022 to 2023. The validation process demonstrated that the model could accurately reproduce observed streamflow, with improvements in simulation accuracy during the validation period compared to the calibration period. This indicates that the model is robust and reliable for simulating streamflow in the Gangotri Glacier Watershed.

Using the corrected climate data and calibrated model parameters, a continuous simulation was performed from 2016 to 2023. The analysis revealed that approximately 90% of the streamflow occurred during the ablation period (May to October), which coincides with the primary monitoring period of this study. The model simulation showed that streamflow peaked during the months of July and August. This peak was primarily driven by the simultaneous contributions of increased glacier melt and rainfall during these months. This finding aligns with field observations, where significant glacier melts and intense rainfall

events were recorded in the region during this period. The contributions of different hydrological components were analysed for each month. Rainfall contributed significantly to streamflow from July to October, while snowmelt contributed mainly from March to June, coinciding with the melting of accumulated snow. The glacier melt contribution, which is heavily dependent on temperature was highest during the months of August and September, when both high temperatures and intense solar radiation cause rapid ice melt. The base-flow component, representing groundwater contributions, remained relatively constant throughout the year, providing a steady contribution to streamflow even during the winter months when glacier and snowmelt contributions were minimal.

The study also observed notable variations in streamflow across the years. The flow variability appeared to increase over the study period, with streamflow sustaining longer into the ablation season. This was particularly evident with more pronounced flow peaks observed in September, indicating a delayed discharge response due to increased glacier melt later in the ablation season. This suggests that warming temperatures and changing precipitation patterns are influencing the timing and magnitude of streamflow in the region. One of the most significant findings of this study is the increasing flow variability observed over the 8-year simulation period. This variability could be attributed to the complex interplay between glacier melt, snowmelt, and rainfall. The influence of localized intense precipitation events, which are becoming more frequent and severe due to climate change, may be amplifying flow variability. These extreme events contribute to higher peak discharges and increased sediment transport during the ablation period, further complicating hydrological dynamics.

The results of this study underscore the critical role of temperature in regulating streamflow in glacierized watersheds. Rising temperatures not only accelerate glacier melt, but also interact with precipitation patterns to intensify flow variability. These findings highlight the vulnerability of glaciated regions to the impacts of climate change, particularly in terms of water availability and flood risks. The increased frequency of extreme precipitation events may also lead to more frequent and severe flood events, posing challenges for water resource management and infrastructure in downstream areas. In conclusion, this study provides valuable insights into the hydrological processes of the Gangotri Glacier Watershed and the sensitivity of streamflow dynamics to climate change. The findings emphasize the importance of accurate climate data, appropriate model calibration, and understanding the role of temperature and precipitation in regulating streamflow. The results also highlight the need for ongoing monitoring of glaciated watersheds to better predict the impacts of climate change on water resources in regions dependent on glacier and snowmelt contributions. These insights are crucial for improving water resource management strategies in the face of a rapidly changing climate.

Keywords: *Streamflow, glacier, Himalaya, climate change, hydrological modelling*

ENVIRONMENTAL ISOTOPES FOR MANAGEMENT OF SPRINGSHED IN THE KHULGAD WATERSHED OF KOSI RIVER CATCHMENT, KUMAUN LESSER HIMALAYA, INDIA

Puthiyottil Nijesh[1], Shive Prakash Rai[1*], Rajesh Singh[2] and Suhas Khobragade[2]

[1]*Department of Geology, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India*

[2]*National Institute of Hydrology, Roorkee, India*

[*]*Corresponding author e-mail: sprai1966roorkee@gmail.com*

The springs are the external face of groundwater, which emerges through fractures or slopes, generally found in mountainous terrains around the world. In India, a total of 5 million springs are identified, out of which 3 million are located in the Indian Himalayan Region (IHR). Spring water is essential for mountain communities, especially those living at the mountaintop without direct access to river water to meet their drinking and domestic needs. Springs sustain the base flow of streams during the lean season. The spring discharges in the Kumaun Lesser Himalayan region are showing a declining trend. The cumulative effects of changing land use trends, anthropogenic activities, and climate change may trigger the dwindling discharge of the springs, leading to an acute scarcity of water. Therefore, it is indeed to delineate the spring recharge zones (i.e., Springshed) in order to rejuvenate the springs in the Himalayan regions. Hence, an attempt has been made to delineate the springshed in the Mattella village of the Khulgad watershed, Almora district, using stable isotopes of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) as well as to understand the recharge processes of the springs.

The stable isotopes (i.e., $\delta^{18}O$ and $\delta^{2}H$) have been widely applied in hydrological studies to trace water origins, movement, recharge source, and interactions within various hydrologic systems, offering crucial insights into these processes. The isotopic signatures of $\delta^{18}O$ and $\delta^{2}H$ in groundwater and precipitation are helpful in estimating the possible altitude of recharge zones. The altitude effect of the precipitation is an important factor which helps to estimate the recharge altitude of the spring water. As water vapor ascends and cools, heavier isotopes (^{18}O and ^{2}H) condense first, leaving the remaining vapor isotopically lighter, a process that leads to precipitation at higher altitudes or latitudes having lighter isotopic compositions. For instance, precipitation from higher elevations or specific seasons may exhibit unique isotopic compositions, which can be traced in groundwater to pinpoint the recharge sources, a critical step for water resource management, especially in regions heavily reliant on groundwater. To investigate these spatiotemporal variations, rain gauges were installed at three different altitudes within the study area for rainwater collection. Event-based rainwater sampling was collected from December 2020 to December 2021, with each sample collected in 15 ml high-density polyethylene (HDPE) bottles, securely capped with an inner lid and screw cap to maintain sample integrity. The regression line of the Local Meteoric Water Line (LMWL) was developed by the rainwater samples collected from the different altitudes. To understand the altitudinal variations of rainfall from different elevations, the isotopic characteristics of the monthly average rainfall have been analyzed for three different altitudes. Isotopic compositions of surface waters (rivers, lakes, canals) and groundwater (springs) often differ due to the unique sources and processes influencing them. By comparing $\delta^{18}O$ and $\delta^{2}H$ values, the interaction between these water bodies can be assessed; for e.g., a river significantly influenced by groundwater input will have an isotopic signature closer to that of the local groundwater. The identified spring of the Mattella village is located at an altitude of 1364 m above mean sea level (amsl) and serves as the sole source of drinking water and domestic needs for the local communities. Geologically, the study area comprises Schist rocks interbedded with the quartzite, which are fractured in nature. A total of 19 rainwater samples were collected from the three stations (Khoont, Sitlakhet, Nainital) at different altitudes. Similarly, the monthly spring isotopic signature was measured. The ^{18}O and ^{2}H signatures of the precipitation and spring are used to estimate LMWL. The monthly isotopic values of precipitation of $\delta^{18}O$ and $\delta^{2}H$ were plotted with the altitude to establish the rain altitude effect.

The altitude effect of $\delta^{18}O$ is 0.28 ‰ per 100 m rise in elevation, and the altitude effect of ^{2}H is 2.2‰ in the 100 m rise in elevation. Based on this analysis, the projected recharge area for the Mattella Spring is identified at an altitude of 1682.1 m amsl, which is approximately 318.1 m above the spring discharge site. Based on the hydrogeological and isotopic studies, it is recommended that recharge pits be constructed in the village of Mattella between the altitude of 1400 and 1682.1 m amsl. to ensure adequate rainwater recharge for the springs. Beside constructing recharge pits, several complementary measures can further augment spring discharge and ensure sustainable water availability for the community, such as contour trenches, additional percolation pits, and check dams that can be strategically placed within the recharge zone. Contour trenches help capture and infiltrate rainwater, while check dams slow down the flow of water, allowing it to seep into the aquifer. Similarly, Nala bunds and percolation shafts can increase the retention and percolation of rainwater. When implemented alongside the recommended recharge site, these additional measures can significantly enhance the spring discharge in the Mattella spring. Also, it is indeed important to involve the stakeholders in the awareness and need for rejuvenation and use their traditional knowledge for spring rejuvenation. A holistic approach combining scientific, ecological, and community-driven strategies ensures sustainable spring water availability for drinking and domestic purposes while preserving the recharge zone for future generations.

Keywords: *Springs, dwindling discharge, rejuvenation of spring, stable isotopes, recharge zone identification*

LAND SURFACE TEMPERATURE DYNAMICS IN A LESSER HIMALAYAN CATCHMENT

Pravin R. Patil*, Harsh Upadhyay, Disha Yadav, M.K. Nema and A.R. Senthil Kumar

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: prpatil.nihr@gov.in*

Land Surface Temperature (LST) is a critical element of the Earth's weather and climate system, influencing energy and water exchanges between the land and atmosphere. It impacts glaciers, permafrost, vegetation, and crop water needs, serving as a key input for weather, climate, hydrological, and ecological models. Designated an essential climate variable by the WMO's in 2016, LST is widely used in weather prediction, evapotranspiration analysis, land use/land cover (LULC) change, drought monitoring and biodiversity research. LST represents the radiative skin temperature of the land, incorporating emissions from bare soil and vegetation canopies. Recognized as a key earth system data record by NASA, it reflects energy partitioning at the land-atmosphere interface and is sensitive to surface changes. Unlike air temperature, LST provides detailed insights into latent and sensible heat fluxes, vegetation density, surface roughness, and transpirational cooling, making it indispensable for understanding surface energy and water balances. The fragile Himalayan foothills, are witnessing abrupt shifts in seasonal patterns and extreme temperature variations, with recent years experiencing unprecedented LST spikes exceeding 49°C. These alarming trends necessitate a comprehensive investigation into the factors driving these changes. This study analyses spatiotemporal variations in LST across the Henval catchment, a minimally disturbed catchment spanning 254 km² in the Tehri Garhwal district of Uttarakhand. The catchment, comprising forested areas, agriculture, and the urbanized region of Chamba, serves as a benchmark for hydrological studies in the Lesser Himalayas. Using multi-temporal satellite (Landsat 8&9) datasets, processed on the Google Earth Engine platform, this study examines LST patterns w.r.t. elevation and longitudinal distance along the valley over four seasons (i.e., pre-winter, winter, summer & monsoon) between 2019-2024. Seasonal mean and 15-day interval LST data were analyzed across four longitudinal profiles mapped using ArcGIS: (i) valley, (ii) left ridge, (iii) right ridge and (iv) a road network connecting both the ridges and running adjacent to a right ridge. The study incorporated Sentinel-2-based LULC dynamics and ASTER-DEM-derived topographical attributes such as elevation and aspect or orientation to contextualize the observed temperature trends.

The annual mean LST shows a notable increase across all four profiles, with mean differences from 2019 to 2024 recorded as 10.24°C (valley), 6.13°C (right ridge), 4.35°C (left ridge), and 5.73°C (road network). The six-year mean LST highlights a ~1°C difference between the left and right ridges, while the valley is significantly warmer, exceeding both ridges by over 13°C. Despite representing valley slopes and a part of the right ridge, the road network's six-year mean LST also surpasses both ridges by nearly 10°C. Seasonal six-year LST averages reveal similar warming patterns for the ridges and road, following the order: winter, monsoon, pre-winter, summer. However, the valley exhibits a different sequence: winter, monsoon, summer, pre-winter. Notably, the difference between six-years summer and pre-winter LST averages is minimal for the valley (0.11°C) and road (0.67°C), but much higher for the left (7.37°C) and right ridges (10.55°C). The overall six-year seasonal mean LST difference is 6.46°C (valley), 14.83°C (left ridge), 12°C (right ridge), and 9°C (road), indicating that ridges and road are more sensitive to seasonal changes compared to the valley.

Additionally, the left ridge and road show a decreasing LST trend with increasing elevation, whereas the valley and right ridge display an opposite pattern over the 2019–2024 period. Abrupt temperature spikes in second half of May 2023 and 2024 indicate intensified summer warming. In May 2023, temperature fluctuation zones were observed: in the valley of 41 km in length (at 27.46–33.78 km from the outlet, elevation 922.32–1437.20 m), on the right ridge of 44 km in length (at 35.71–39.47 km, elevation 1368–1871 m), and on the left ridge of 43.5 km in length (at 2.52–5.37 km, elevation 1492–1513 m). By May 2024, these warming zones expanded, reflecting increased warming at both lower and higher elevations in the valley and left ridge, while shifting to higher elevations along the right ridge. The catchment elevation ranges from 379.83–1983.2 m above mean sea level (amsl) in the valley and 379.83–2673 m amsl for the ridges. To analyse LST fluctuations during the second half of May in 2023 and 2024, buffer zones were created, considering the extreme elevation points/width of identified fluctuations zones covering the area on either sides within a radius of 5 km for the valley (flat terrain) and 2.5 km for ridges (accounting for walkable distances in hilly areas). From 2019 to 2024, 15-day LST of second half of May 2023-24 data showed a consistent trend of decreasing temperatures with rising elevation in the valley and road profiles, with similar behavior on the right ridge, except in 2020 and 2024. However, the left ridge disrupting typical temperature-elevation relationships and exhibited a significant shift starting in 2021, with temperatures increasing with elevation, reversing the trend from 2019–2020. These variations may result from localized LULC changes such as deforestation, urbanization, the presence of water bodies/springs, or microclimatic factors like anabatic-katabatic flows, diurnal heating and nighttime radiative cooling. In contrast, the valley's stability suggests minimal climatic disruptions and efficient diurnal heat retention.

LULC dynamics was analyzed and assessed anthropogenic influences within defined buffer zones. On the right ridge, five LULC classes namely forest, agriculture, built-up, barren land, and range land were identified, whereas the left ridge and valley had four classes, lacking agriculture and barren land, respectively. From 2019 to 2023, the right ridge experienced a substantial 14.7% increase in built-up areas, rising from 18% to 32.7%, with the highest growth (3.8%) occurring between 2023 and 2024, reaching 36.5%. Similarly, the left ridge reflects built-up areas increase from 25% (2019) to 31% (2024). In the valley LULC changes are more prominent, as agriculture declined from 20% to 14%, built-up areas rose by 13.1% (28% to 41.1%), and range land decreased by 6% (44% to 38%). Other LULC classes on both ridges showed a consistent decline over the five years. These intensified anthropogenic activities and reductions in vegetative cover correlate with the temperature increases observed in 2023–2024: 2.59°C in the valley, 1.53°C on the right ridge, and 1.28°C on the left ridge. Analysis of aspect or orientation using DEM revealed that 52% of the right ridge area is sunlit, with 24% in the opposite direction. For the left ridge and valley, sunlit areas account for 39% and 38%, while shaded areas comprise 30% and 32%, respectively. Thus, by integrating LST trends, LULC changes, and topographical factors, this study identifies key drivers of regional warming and extreme temperature variations in the Himalayan foothills. These findings not only inform adaptive strategies and climate resilience efforts in this ecologically sensitive region but also provide a framework for future research. By connecting localized observations with broader climatic trends, the study highlights the need for proactive measures to protect vulnerable ecosystems and communities amid accelerating climate change.

Keywords: *Land surface temperature, Himalayan catchment, LULC*

SPRING REJUVENATION FOR WATER SECURITY IN HIMALAYA: A HOLISTIC APPROACH

Tarun Pant[1&3*], Rohan Singh Bhakuni[2] and Vaibhav E. Gosavi[3]

[1]*Indian Institute of Technology, Bombay, Mumbai, India*
[2]*PASS, Pithoragarh, Uttarakhand*
[3]*G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand*
[*]*Corresponding author e-mail: pantarun315@gmail.com*

The Himalayan ecosystem is increasingly vulnerable to adverse impacts from changing climate patterns, intensified anthropogenic activities, land degradation, and shifting land use and land cover. These factors significantly threaten the region's natural water availability, particularly spring water resources, which serve as a lifeline for local communities. Over the years, these springs have experienced severe depletion, posing a critical challenge to water security in the region. To combat this issue, a study was undertaken in the Lohaghat block of Champawat district, Uttarakhand, with the primary goal of revitalizing drying springs in mountainous areas. These springs are essential for meeting the daily water needs of local communities, who rely heavily on them. The project adopted a participatory approach, actively engaging relevant line departments, organizations, and local communities. This initiative underscores the importance of community involvement and the integration of local knowledge and traditional practices and scientific methods to ensure sustainable water resource management in the area. The study began with a preliminary survey of the area, identifying nine key spring sources for detailed analysis. The methodology was organized into three primary stages: data collection, identification of potential recharge zones, and water augmentation interventions, supported by robust hydrological and statistical analyses. To monitor spring discharge, two methods were employed (i.e. the Bucket and Stopwatch Method and the Water Level Drop Method), enabling accurate yield measurement per minute for each spring. Additionally, three rain gauges were installed at varying elevations to gather rainfall data at regular intervals, resulting in a comprehensive three-year dataset that provided reliable insights into spring discharge and rainfall patterns. For identifying potential recharge zones, a combination of hydro-geological investigations, remote sensing techniques, and isotope analyses was employed. Geological studies involved detailed assessments of lithology, structural geology, topography, and geological contacts. Remote sensing techniques utilized the Analytic Hierarchy Process (AHP), integrating geological, hydrological, and catchment parameters to map groundwater recharge zones effectively. To corroborate these findings, isotope analysis of stable oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}D$) isotopes in spring and rainwater samples was conducted, enhancing the understanding of recharge processes and water sources.

Interventions for water augmentation were focused on improving groundwater infiltration and reducing surface runoff. Structures such as trenches, toe trenches, and percolation pits were constructed in identified recharge zones to capture rainwater and channel it into aquifers. The effectiveness of these interventions was assessed through a detailed analysis of spring discharge data before and after the interventions. Hydrological tools, including hydrographs, master recession curves, and flow duration curves, were combined with statistical approaches like bivariate and multivariate analyses, providing insights into changes in discharge patterns and aquifer health. Community involvement was integral to the project, with awareness programs and capacity-building initiatives conducted to promote sustainable

water resource management. Para-hydrologists were trained to monitor spring discharge continuously, ensuring the long-term sustainability of the interventions. Through these multifaceted efforts, the study aimed to secure and enhance the water resources of the region effectively. The application of the outlined methodology to address water scarcity in the Manadunga villages delivered promising outcomes. The spring delineation studies identified that approximately 70% of the study area falls under moderate to good recharge potential, highlighting suitable zones for intervention. Based on these findings, over 500 recharge structures, including trenches, percolation pits, and ponds, were constructed in the identified zones with active community participation. These structures effectively captured surface runoff and directed rainwater toward areas ideal for groundwater recharge, significantly enhancing infiltration rates. The hydrological analysis demonstrated the success of these interventions. Despite reduced rainfall compared to the previous year, the average discharge of heavily utilized springs increased from 5.37 liters per minute (lpm) to 6.86 lpm. This improvement reflects the effectiveness of the recharge structures in maintaining and enhancing spring discharge. The results confirm the technical viability and impact of combining geological, hydrological, and community-driven approaches. It also emphasizes the importance of targeted recharge interventions in mitigating water scarcity and ensuring the sustainability of vital spring resources, even in fluctuating climatic conditions. Despite adverse rainfall conditions, the project demonstrated the effectiveness of rejuvenation efforts in enhancing spring discharge, particularly at the initial stage. This success underscores the potential for continued interventions to further improve water security in the region. Community involvement was central to the project's achievements, with capacity-building programs raising awareness about the importance of springs and their ecosystems. These efforts also trained para-hydrogeologists for long-term spring monitoring and sustainable water management. The integration of scientific techniques, such as hydrogeological studies, remote sensing, and isotopic analysis, with grassroots community participation, proved to be a promising strategy for spring rejuvenation. This approach ensures reliable water availability while promoting environmental sustainability. The study exemplifies a holistic method to tackle water scarcity challenges, offering long-term benefits for both the environment and the local population. Also, it sets a replicable model for similar regions facing water security issues.

Keywords: *Spring rejuvenation, Himalayas, mountain groundwater, water scarcity, hydrological assessment, remote sensing and GIS*

MORPHOMETRIC ANALYSIS FOR PRIORITIZATING SUB-WATERSHED OF KARLI RIVER BASIN USING GEOSPATIAL TECHNIQUES

Tanvi Khandekar[1]*, Athira Prakash[1], Kumar Amrit[1,2], Paras R. Pujari[1,2] and Shalini Dhyani[1,2]

[1]*CSIR- National Environmental Engineering Research Institute, Nagpur, India*
[2]*Academy of Scientific and Innovative Research (AcSIR), Gaziabad, India*
**Corresponding author e-mail: khandekartanvi@gmail.com*

Watersheds are critical geographical units for understanding hydrological processes and planning sustainable water and soil resource management strategies. The present study investigates the Karli watershed, located in the Sindhudurg district of Maharashtra. The present study leverages GIS and Remote sensing tools to carry out a detailed morphometric and LULC analysis of the watershed for prioritizing its sub-watershed based on their susceptibility to soil erosion and surface runoff. Thirteen sub-watersheds were delineated and analyzed to provide insights into their physical characteristics and land cover dynamics, facilitating better decision-making for watershed management and conservation. The study aims to get a brief hydrological understanding of Karli watershed. The drainage area of watershed is approximately 778.3 km^2 and exhibits a dendritic drainage pattern. The linear, areal and relief aspects of morphometric parameters have been estimated for all the thirteen sub watersheds. The SRTM DEM (30 m resolution) was used to delineate the watershed and generate the drainage network. The morphometric characteristics of each sub watershed have been analyzed using GIS and remote sensing techniques. The parameters analyzed for linear aspect were stream order, stream count, stream length, stream length ratio, bifurcation ratio, average bifurcation ratio, mean stream length, average stream length, stream frequency, drainage density, drainage texture, length of overland flow, rho coefficient, drainage intensity, infiltration number, and constant of channel maintenance. The parameters analyzed for areal aspect were area of the watershed, perimeter of the watershed, basin length, circulatory ratio, elongation ratio, form factor, lemniscate ratio, shape index, and compactness coefficient. The parameters analyzed for relief aspect were maximum elevation, minimum elevation, relief, relief ratio, relative relief, ruggedness number, and hypsometric analysis.

Sub-watershed with higher relief and linear parameters, i.e. SW-3, SW-6, SW-8, SW-10 SW-11, and SW-13 were ranked as high priority due to their susceptibility to runoff and soil erosion. Conversely, SW-1, SW-7 and SW-9, with lower values, were ranked as low priority, indicating relatively stable condition with minimal vulnerability to degradation. The drainage density of the watershed was found higher at SW 4 (2.65) and lower at SW 9 (1.49), highlighting variation in runoff potential and infiltration rates across the sub-watersheds. Bifurcation ratios varied significantly, with the highest value (34.52) for SW-7, indicative of a structurally controlled drainage pattern, while SW-12 had the lowest value (4.29), reflecting a more stable drainage configuration. The ruggedness number, a key indicator of terrain ruggedness and soil erosion potential, was highest in SW-6 and lowest in SW-5, further emphasizing the diversity in geomorphological characteristics within the watershed. These variations underscore the importance of prioritizing conservation efforts in sub-watersheds with higher runoff and erosion risks. The study carried out for LULC characterization reveals that, the agricultural land constitutes significant portion of the watershed, particularly in SW-12, which is predominantly covered by crops such as cashew, coconut, paddy, and sugarcane. The extensive soil cover makes SW-6 highly susceptible to soil erosion, especially in the

absence of adequate soil conservation practices. SW-8 has the highest forest cover (90%), which plays a critical role in stabilizing soils, enhancing infiltration, and regulating runoff. In contrast, SW-12 has minimal forest cover, exposing it to heightened vulnerability. Built-up areas were most prominent in SW-1, reflecting urban development pressures, while SW-8 showed the least built-up land, emphasizing its natural character. The findings further indicate that SW- 6 has substantially minimal forest cover, is challenged by its high ruggedness and steep slope, necessitating runoff management studies. Waterbodies are sparse across most sub-watersheds but played a crucial role in SW-9 and SW-11, where their presence mitigates runoff and supports groundwater recharge.

The integration of morphometry and LULC analysis provides robust framework for prioritizing sub-watershed and tailoring, management strategies. According to the data of morphometric analysis, SW 3, SW 6, SW 8, SW 10, SW 11 and SW 13 have the highest priority, and SW 2, SW 4, SW 5, SW 12 have the medium priority while SW 1, SW 9, SW 7 have the lowest priority among sub-watersheds. According to morphometric and LULC analysis, sub-watersheds, SW 3 is the common sub-watershed that fall within high priority. SW 4, and SW 5 has medium priority. Although morphometrically SW 6, SW 11, and SW 13 has high priority but as per LULC analysis it comes under the sub-watershed for medium priority. The present study highlights the significance of tailored land management practices. Sub-watershed with high agricultural activity, such as SW 5 and SW 12, should adopt conservation farming techniques, while heavily forested regions, like SW-8 required strategies to balance run-off control and ecological preservation. Urbanized area in SW-1 must incorporate green infrastructure to mitigate the impacts of the watershed and the socio-economic well-being of its communities. The integration of morphometry and LULC analysis in the study provides a holistic framework for prioritizing sub-watersheds based on their vulnerability to soil erosion, runoff and degradation. The results emphasize the need for targeted interventions in high-priority areas and proactive management in medium and low priority zones. By addressing specific vulnerabilities, this research contributes to sustainable watershed management, ensuring the ecological and socio-economic health of the Karli watershed. The study reinforces the value of GIS and remote sensing as indispensable tool for informed decision-making in environmental management.

Keywords: *Watershed management, morphometric analysis, GIS and remote sensing, LULC classification, watershed prioritization*

DEVELOPMENT OF SPRINGS IN HILLY TERRAINS – A CASE STUDY IN WEST SIANG DISTRICT, ARUNACHAL PRADESH, INDIA

S. Somarendro Singh*, Tapan Chakraborty, Biplab Ray, Dhrubajyoti Khanikar, Dipjyoti Khound, Chao Konseng Gogoi and Himangshu Kachari

Central Ground Water Board, North Eastern Region, Guwahati, India
**Corresponding author e-mail: sssorokhaibam312@gmail.com*

Since time immemorial, springs have emerged as the most dependable source of water in hilly areas. Spring water which is primarily a component of groundwater. However, it is difficult for storage logistically in hilly terrains. As spring water forms the lifeline of the hilly communities, revival of the age-old traditional source of this water is crucial for sustainable growth and development of the hilly areas. A large share of the groundwater flux ends up in springs and consequently in rivers. Therefore, it is imperative that river rejuvenation becomes immaterial without a clear focus on spring revival based on the fact that reinstatement of river waters throughout the year is due to their discharges received from groundwater as springs or seeps along their channels. The groundwater discharge from aquifers to river channels are recognized as the base flow of such rivers during lean period. Therefore, a depletion in spring water affects flows in rivers thereby revival of springs become tremendously significant in rejuvenation and restoration of the rivers. West Siang district in Arunachal Pradesh is predominantly hilly terrain. The 99% of the district is occupied by hills having maximum elevations of 5248 m above mean sea level (amsl). Out of this, 20% area remains permanently snow bound. The climate is sub-tropical humid in nature and the average rainfall recorded in the district is 2463.95 mm. The soils are fertile and suitable for paddy cultivation. Siyom river and its tributaries form the main drainage system of the district. The future irrigation and domestic water requirements in such hilly terrain can be met through systematic development of springs with a holistic approach and realistic awareness.

In this paper, a case study regarding development of springs in the hilly terrain of West Siang District of Arunachal Pradesh is highlighted based on field data. A preliminary study of these springs comprising spring inventory, classification of the springs, their discharges and preparation of a conceptual layout of the springs delineating their source of recharge, recharge area and their relationship with local aquifer system. The methodology includes both field and laboratory investigations. The field investigations include spring inventory and measurement of discharge of the springs and sampling of spring water while, laboratory investigations consist of chemical characterization of spring samples and desk analysis includes map preparation, making relevant diagrams, etc. Geotagging of springs done by using hand held GPS. Survey of India Toposheet of 1:50000 scale and satellite imageries downloaded from Google Earth have been used during mapping. Based on the various hydrogeologic data, conceptual diagram of the springs indicating recharge and discharge area were prepared. The discharge of springs was measured using a container of known volume and a stopwatch. Base line details have also been recorded through interaction with local people especially village heads. Puakghat Natural Calamities Welfare Society (PNCWS), Along, West Siang district, Arunachal Pradesh, one of leading organization was involved to make the villagers aware about the springs in an informal way.

It has been observed that the amount of discharge of the springs remain sufficient even during lean periods which can be harnessed efficiently for providing stable and low-cost water

supplies for domestic as well as irrigation purposes. Fifty (50) springs with varied discharges were recorded for detailed study. Discharge rate of springs have been found varied with the change in lithology. The discharge rate varies from 1.7 LPM to 57.77 LPM during pre-monsoon and it varies from 1.38 LPM to 55.63 LPM during post-monsoon period. Based on the hydrogeologic data of springs inventories and discharge data, thirty-three (33) springs were categorized as Perennial (66%) and seventeen (17) were as intermittent (34%) category. As per the Meinzers' classification, thirteen (13) springs have been classified under the 6th class-magnitude and twenty (20) springs in the 7th class-magnitude. In West Siang district, the existence of groundwater is found to be manifested in the form of springs. Storage and movement of springs are controlled by joints/fractures as secondary porosity. The discharge of springs varies between 1.38 LPM and 57.77 LPM in the district. All the chemical constituents of the springs were found within permissible limits of BIS for all uses. It is obvious that supply from single running water points of springs culminates in scarcity of water specially during lean period resulting in decline in spring discharges and sometimes even drying up. Obviously, sources of water supply go dry due to overload. It is necessary to develop springs systematically to meet the future requirements of the population. Scientific development of springs, diversion of stream water to reservoirs, storage and settling tanks are important. Inculcating regular practices to check the debris and mudflows during rainy seasons to get copious water throughout the year in such a hilly terrain is an important effort to be initiated. Cleaning the flow path of springs and construction of collecting tanks wherefrom the water should be drawn into the storage tank for distribution should be developed.

Keywords: *Springs, West Siang, hydrogeology, base flow, Meinzers' classification, spring inventory*

HYDROCHEMICAL ANALYSIS OF SPRINGS WATER IN PRATAPNAGAR BLOCK, TEHRI GARHWAL OF UTTARAKHAND, INDIA

Ayush Kukreti[1&2], S.S. Rawat[1*], D.S. Malik[2] and Tanveer Dar[1]

[1]*National Institute of Hydrology, Roorkee, India*
[2]*Gurukula Kangri (Deemed to be University), Haridwar, Uttarakhand, India*
[*]*Corresponding author e-mail: ssrawat.nihr@gov.in*

Groundwater-fed springs, locally referred to as *Naulas* and *Dharas*, serve as the primary water supply in thousands of mountainous villages of Uttarakhand state of India, where alternative sources are often limited due to the region's geomorphology and topographical constraints. Pratapnagar block, located in the Tehri Garhwal district of Uttarakhand, India lies between 30° 23'N to 30° 37'N latitude and 78° 24'E to 78° 34'E longitude, with elevations ranging from 800 m to 2,400 m, above mean sea level (amsl). The region experiences a monsoonal climate, with the majority of rainfall occurring from June to September. However, Pratapnagar is facing increasing water scarcity due to declining groundwater levels and drying springs, highlighting the urgent need for sustainable springshed management in the area. In the present study, 50 springs were identified within the boundary of Pratapnagar block in major settlement areas, and water samples were systematically collected for analysis. Key parameters, including spring location, dependency, usage, discharge rates, and historical data based on local perceptions were documented during field surveys. In-situ measurements of physical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and oxidation-reduction potential (ORP) were recorded in the field. Samples for the analysis of major cations-anions, trace metals, and Alkalinity tests were collected and subsequently analyzed in the Water Quality laboratory of the National Institute of Hydrology, Roorkee. A key aspect in determining the main determinants of the water quality of the springs in the research region was the statistical analysis of the data that was gathered. Through the use of statistical techniques including regression modeling, analysis of variance (PCA), and correlation analysis; important connections between several environmental factors and water quality metrics were found. Both natural processes including geochemical interactions with underlying bedrock, and anthropogenic activities, like agricultural activities and waste disposal from the settlements, have an impact on the quality of water.

Concentrations of CO_3^{2-} and HCO_3^- were measured through the titration method by using unfiltered samples on an Auto-titrator with 0.02N H_2SO_4. Major ions such as Fluoride (F^-), Chloride (Cl^-), Sulfate (SO_4^{2-}), Phosphate (PO_4^{3-}), Nitrate (NO_3^-), Sodium (Na^+), Potassium (K^+), Ammonium (NH_4^+), Magnesium (Mg^{2+}), and Calcium (Ca^{2+}), were analysed using an Ion Chromatography (IC) calibrated with the standards, with results reported at an analytical precision of ±5%. Each sample was diluted 10 times with Milli-Q water (resistivity of 18.2 MΩ) to ensure ionic concentrations were within the instrument's sensitivity range. Aliquots of 60 ml samples were collected for trace metal analysis, focusing on major trace metals such as lead (Pb), zinc (Zn), arsenic (As), cadmium (Cd), nickel (Ni), boron (B), Aluminium (Al), Chromium (Cr), Manganese (Mn), and iron (Fe) by using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The springs in the Pratapnagar block are characterized as sixth-magnitude springs as per Mainzer's classification based on the average discharge of the spring, with discharge ranging from 1 to 10 gallons per minute (approximately 0.0063 to 0.063 liters per second). 85% of the springs are located at elevations above 1000 m, amsl while only 15% springs at altitudes below 1000 m.

It was observed during the survey that 68% of the surveyed springs are highly dependable source for the local populace, 27% as moderately dependable, and only 5% as low dependable. In terms of water quality, 85.5% of the springs exhibited a pH within the permissible range of drinking water i.e., 6.5 to 8.5, while 11.5% were slightly acidic (pH < 6.5), and 3% were slightly basic (pH > 8.5). Electrical Conductivity (EC) measurements revealed that 71.2% of the springs have EC values less than 150 µS/cm, 20.2% springs fell within the range of 150 to 300 µS/cm, and only 8.5% springs exceeded 300 µS/cm. EC measurements, a key indicator of dissolved ionic content, revealed that EC values below 150 µS/cm, signifying low mineralization and suitability for drinking. Additionally, higher EC values indicate higher mineral content potentially resulting from geological formations or anthropogenic influences such as agricultural runoff. Springs with higher EC levels may require additional treatment or monitoring to maintain drinking water standards. These findings provide valuable insights into the hydrological characteristics and water quality of the springs in the region. To evaluate the general health of springs, the Water Quality Index (WQI) is a numerical expression that condenses complicated water quality data into a single value. It is also useful to determine the suitability of springs water for drinking, irrigation, or other uses. The WQI offers a consistent method for evaluating the quality of water in various locations. Policymakers and environmental managers utilize it extensively to make decisions. Better water quality is indicated by a lower WQI score, whereas higher values suggest possible hazards and the need for corrective action. The estimated values of the WQI for the surveyed springs indicate the suitability of water for drinking purpose, with the present data categorized as excellent, yielding a WQI of 39.5. However, periodic measurements of the springs are to be needed to understand the effect of climate change and anthropogenic activities on the vital water resources of the mountainous area.

Keywords: *Spring, hydrochemical analysis, Pratapnagar block of Uttarakhand, Mainzer's classification, Water quality index*

PAST, PRESENT AND FUTURE OF SPRINGSHED MANAGEMENT IN INDIA

S.S. Rawat*, Deepak Singh Bisht, Santosh M. Pingale and Tanveer Dar

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: ssrawat.nihr@gov.in*

Springs are critical and dependable sources of water security for the population of mountainous regions across world (e.g., India, USA, New Zealand, Ethiopia, Turkey, Spain and Greece). A gross estimate of nearly 200 million Indians depends on spring water mainly in the Indian Himalayan Region (IHR), Western Ghats (Sahyadri mountain range, traversing the states of Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu), Eastern Ghats (Northern Odisha, Andhra Pradesh, and Tamil Nadu) and Central India (Satpura and Vindhyas mountains). Springs are also one of the most cost-effective ways to provide relatively pure water in entire mountainous parts of the country as rivers are flowing in the deep valley and glacier are far flung, so water from these two sources is economically not feasible. In addition to this, these springs sustain several rivers, particularly in the lean season and there is hardly any river throughout the globe, which is not feed by a spring. However, climate change, deforestation, and unsustainable development practices are putting immense pressure on these springs. During 1961–2011, the Himalayan population grew by 250% with an annual growth rate of 3.3%, which is three times the world average growth rate. This rapid growth led to accelerated urbanization eventually causing the damage to recharge zones and degradation of water quality of the springs. Furthermore, this population surge has placed significant stress on these vital water sources. As a result, over the past few decades numerous springs have either dried-up or became seasonal.

In India, Govt. of Sikkim implemented a community-based programme i.e., Dhara Vikas Programme (first ever springshed management programme in the country) with the help of International Organization (ICIMOD, WWF, gIZ, UNDP) Central/State government Scientific Organization (BARC, ISRO, Land Resource), NGOs (ACWADEM, ARGHYAM, PSI, etc.) and other scientific institutes. Under this programme 50 springs, 5 lakes and 7 Hill top Forest was revived. Department of Land Resources, Nagaland initiated a one-year pilot programme to work on one spring in each of the State's 11 districts involving the local communities. Programme has so far benefitted more than 600 households with increased availability of water, especially during the summers. National Institute of Hydrology (NIH) Roorkee, a Research and Development (R&D) organization under the Ministry of Jal Shakti, Govt. of India identify 40+ parameters, which are necessary for the successful implementation of a springshed programme. NIH has developed a digital data collection system named ISHVAR (Information System of Himalayan Springs for Vulnerability Assessment and Rejuvenation) using open-source technology for geotagging and survey of the springs through mobile. Spring mapping of high social relevance areas has been performed in Western Himalayan region. Till now, 981 springs of Ravi River catchment of Himachal Pradesh (drainage area 5400 km^2) and 469 springs of Tawi River catchment (drainage area 2100 km^2) have been mapped for 40+ parameters.

In year 2022, the Ministry of Jal Shakti, Government of India, constituted a steering committee of domain experts to initiate and monitor the systematic mapping/geotagging of springs across the mountainous regions of the country and develop a coordination mechanism among various stakeholders to expedite springshed management efforts in India. The committee, through stakeholder meetings and brainstorming workshops, gained an understanding of the tools and techniques employed by agencies working in the field of springshed management in the country. The committee compiled information on over 48,000 geotagged springs in India and identified potential districts for spring occurrence. Consequently, the Ministry of Jal Shakti, Government of India, initiated the First Spring Census of the Country in August 2023. The steering committee has also produced a resource book on springshed management to aid implementing agencies and encourage research on spring hydrogeology. CGWB has included the springshed management in its annual programme and monitoring discharge (four times in a year) of nearly 100 springs. The yield of these springs can be helpful to assess the ground water estimation resources in the hilly area. However, the final decision can be taken after long term measurements of the spring discharges in different mountainous region of the country. In the year 2023-24 CGWB has taken up 10 studies for springshed mapping and management under NAQUIM 2.0 studies. A Scheme has already been proposed for rejuvenation of 25,000 springs. On the recommendations of NITI Aayog, rejuvenation of Springshed has been incorporated as a new activity in the WDC-PMKSY 2.0 (Project period 2021-26). Under Springshed Development-Regeneration of springs, Springshed development is to be taken up as an activity under new generation watershed projects to mitigate spring water depletion in the Himalayas and other ‘springscapes’ of India. All state agencies particularly in hilly areas of the country are now giving springshed development adequate place in their Annual Action Plan (AAP) of the development. However, capacity building in the field of springshed management is still a major hurdle to upscale the springshed management programme in the country.

Keywords: *Spring, springshed management, Dhara Vikas programme, ISHVAR, Ministry of Jal Shakti*

DYNAMICS AND CLIMATIC CHANGES IN LARGE-SCALE EXTREMES IN THE NORTHWEST HIMALAYA: IMPLICATIONS FOR REGIONAL HYDROLOGY AND DISASTER RISK

Ashwini Ranade*

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: ranadeashwini@gmail.com*

The Himalayan mountains serve as vital water reservoirs, sustaining millions downstream. However, in recent decades, the region has experienced unprecedented heavy rainfall, leading to devastating floods, landslides, and socio-economic losses. These events highlight the complex interplay between climate change and large-scale atmospheric systems. The northwest Himalayas, with their highly complex terrain and tropical-extratropical interactive atmosphere, are particularly prone to such extremes, especially during the monsoon season. They pose severe risks to the fragile ecosystem, traditional hydrological cycles and local communities. Research suggests that multiple factors driven by climate change contribute to extreme rainfall events. Interactions between deep westerly troughs, cross-equatorial Indian Ocean south-westerlies, and Pacific easterlies create large and intense monsoon troughs extending from the Philippines to the Indus Basin. These phenomena that involve confluence and convergence of huge air masses of contrasting characteristics are short-lived, resulting in rapid condensation and intense rainfall due to the confluence of contrasting air masses over the subtropical mountainous terrain.

The Himalayas exhibit distinct circulation dynamics between monsoonal and non-monsoonal weather systems, with significant seasonal variability. Even within the monsoon period, rainstorm dynamics differ across early, established, and withdrawal phases, complicating the identification of common patterns for extreme rainfall event occurrences. This study addresses these complexities through a comprehensive long-term analysis of large-scale extreme rainfall events (EREs) in the northwest Himalayas (NWH), covering Uttarakhand (UK), Himachal Pradesh (HP), and Jammu and Kashmir (JK). It focuses on three key aspects of these extremes: rainfall magnitude, spatial extent, and event duration using high-resolution (0.25° x 0.25°) gridded daily rainfall data. To explore the drivers of severe EREs, the study analyzes meteorological anomalies and physical processes using NCEP-CFSR-V2 reanalysis data of key atmospheric parameters such as temperature, pressure, geopotential height, wind fields, and absolute vorticity. Inter-annual variations in area averages of annual and seasonal rainfall are studied using Mann-Kendall (MK) test for its trend detection. Spatial variation in long-term trends in grid-scale EREs across the NWH states are also studied by using MK test. An objective criterion has been developed to identify the 1- to 5-day large-scale long-period extreme rain events (LS-EREs) for each year. The criteria use the daily mean rainfall (DMR) during a normal monsoon period as the threshold and the area under wet condition to determine areal extent. Anomalous meteorological conditions during LS-EREs are studied using composite analysis of top three EREs recorded during the study period.

The analysis reveals distinct rainfall trends across the NWH states over the period, with notable variations in recent decades: (i) In *UK*, no significant long-term trend is observed in the annual and monsoonal rainfall series. However, October–November (OND) rainfall exhibits a significant long-term decreasing trend. Over the past 20 years, OND rainfall has declined sharply by 35% compared to the preceding 51-year period. (ii) In *HP*, a significant

long-term decreasing trend is observed in annual rainfall over the 1951–2021 period. Seasonal rainfall patterns, however, remain mostly homogeneous and random. Over the last 20 years, annual rainfall in HP has decreased by approximately 13%, with declines of ~8.5% in monsoonal rainfall, ~33% in OND, ~17% in January–February (JF), and ~17% in March–May (MAM) rainfall. (iii) In *JK*, JF rainfall shows a significant long-term increasing trend over the study period, while annual and other seasonal rainfall series remain largely homogeneous and random. Over the past 20 years, however, monsoonal rainfall in JK has increased by approximately 18%. The LS-EREs intended to quantify the severity of persisting intense rains causing severe flood and damage. For NWH as a whole, while no significant change is observed in the rainfall amount (RA) of EREs, notable changes have occurred in other metrics over the past 20 years. The areal extent (AE) of 1- to 3-day LS-EREs has significantly increased by 28–43%, and the rainwater (RW) contribution of 1-day EREs has risen by 16%. At the state level the trend varies significantly: (i) In UK, RA of EREs of different durations increased by 10-23% and RW by 14-34%; (ii) In J&K, RA of 1-day ERE increased by 16% and RW by 23%, while AE of EREs of different durations by 19-23%; (iii) In HP, RA of EREs of various durations decreased by 10-20% and RW by 14 to 19%. Most of the year-wise most severe LS-ERE-RW events occurred during the monsoon season, however, surprisingly in some years, the severity of non-monsoonal extremes surpassed the monsoon extremes especially in HP and J&K.

The spatial analysis of long-term trends in grid-scale EREs reveals contrasting patterns across the NWH. High-altitude areas, particularly in J&K and northern UK, are experiencing increased rainfall amounts for short-duration (1–3 day) EREs. In contrast, mid- and low-altitude regions in HP and southern UK show significant decreases in rainfall amounts across most durations. Low-intensity EREs are widespread, with higher frequencies in J&K, while high-intensity EREs (>8 times the DMR) are less common and concentrated in northern J&K and high-altitude southern areas of HP and UK. These trends highlight a shift toward more frequent and intense short-duration EREs in high-altitude regions, particularly in J&K and northern UK, alongside a decline in moderate-intensity events in lower-altitude areas like HP and southern UK. Wintertime most severe LS-EREs are largely associated with deep western disturbances, significantly modulated by interaction with the south-westerly jet stream, however, persistence in temperature and circulation anomalies are observed to be strongly linked to the occurrences of LS-EREs during monsoon season. The unusual and abrupt warming of the upper troposphere in the Tibet and Turkey sectors promotes the development of deep troughs and reinforced ridges in subtropical westerlies. The abrupt intensification of the monsoon circulation connected to this warming causes catastrophic spatio-temporal rain events across NWH. This study provides insight into the changing patterns of large-scale extreme rainfall events in the Himalayas, which significantly impact river flows, groundwater recharge, and reservoir management. The results will be helpful for predicting flood risks, planning for sustainable water resource allocation, and improving the resilience of hydrological systems to climate-induced changes.

Keywords: *Large-scale extremes, extreme rain events, Himalayan extremes*

HYDROCHEMICAL ASSESSMENT OF WATER RESOURCES OF THE HENVAL CATCHMENT, TEHRI GARHWAL, UTTARAKHAND, INDIA

Dharm Singh Meena[1*], D.S. Malik[1], S.S. Rawat[2] and Ayush Kukreti[2]

[1]*Gurukula Kangri (Deemed to be University), Haridwar, Uttarakhand, India*
[2]*National Institute of Hydrology, Roorkee, Uttarakhand, India*
[*]*Corresponding author e-mail: dharmifs09@gmail.com*

Innumerable water resources of the Himalayan region, particularly natural springs, streams, and rivers, play a crucial role in sustaining water demands of local communities and ecosystems. Springs, as a primary and reliable year-round water source, are also vital for agriculture, especially in regions where irrigation is largely dependent on natural sources. In fact, these springs are the backbone of local livelihoods, providing water for both domestic use and crop irrigation. Streams and rivers, while important, play a secondary role in comparison to springs in maintaining the region's ecological balance, supporting biodiversity, and ensuring water security in the region. These water bodies also hold significant cultural and spiritual values, with springs often revered in local traditions. The combination of springs, streams, and rivers are indispensable to the region's agricultural, ecological, and cultural well-being, where springs being the most dominant and essential source. The Henval River watershed, extending up to Jijali in the Upper Ganga Basin, Uttarakhand, encompasses two paired catchments: a forested, undisturbed area and an agricultural watershed influenced by anthropogenic activities, including Chamba's semi-urban habitat. Spanning 102 km² between 30°17'N–30°26'N latitude and 78°16'E–78°25'E longitude, the area experiences temperate Himalayan climatic conditions with annual rainfall ranging from 1200 to 1800 mm and an elevation gradient of 999–2676 m, amsl. It transitions from subtropical forests to temperate mixed forests dominated by pine, offering diverse ecological features. The forested sub-catchment, covering 26 km², serves as a crucial drinking water source for 87 villages, while the 76 km² agricultural area highlights human-induced landscape changes, making the watershed a modal representative site for studying hydrological and ecological dynamics in the Himalayan region.

The physicochemical characteristics of water resources in the Henval catchment of Tehri Garhwal, Uttarakhand, were assessed by collecting and analyzing water samples. A total of 34 samples were collected. These included 21 spring's samples, 10 stream's samples, and 3 river's samples. The study aimed to evaluate key parameters to understand the quality and dynamics of the region's various water resources. Spring water samples exhibited discharge rates ranging from 1.06 to 22.39 litres per minute (LPM), temperatures between 13.4°C and 25.3°C, electrical conductivity (EC) of 60.5-296 µS/cm, total dissolved solids (TDS) of 42.7-190 mg/L, salinity of 33.6-644 ppm, dissolved oxygen (DO) levels of 7.1-9.6 mg/L, and oxidation-reduction potential (ORP) values of 22-279 mV. Stream water samples were characterized by discharge rates of 150-12951 LPM, temperatures of 18.9°C-27.8°C, EC values of 84.5-469 µS/cm, TDS levels ranging from 60 to 333 mg/L, salinity between 44-225 ppm, DO concentrations of 7.1-10 mg/L, and ORP values spanning 46-151 mV. River water samples demonstrated higher values for all parameters, with discharge rates between 1500-36853 LPM, temperatures of 24.9°C-28.9°C, EC values ranging from 115-436 µS/cm, TDS levels of 82.5-308 mg/L, pH of 7.62-8.35, salinity of 59.1-211 ppm, DO levels of 7.2-7.3 mg/L, and ORP values of 99-108 mV. Water samples were analyzed for cation, anion, trace metal concentrations, and alkalinity in the lab of National Institute of Hydrology, Roorkee to

assess the quality of spring water in the study area. To identify the primary determinants of water quality, statistical techniques including regression modeling, principal component analysis (PCA), and correlation analysis were applied to the collected data.

Results indicated that both natural geochemical processes and anthropogenic activities, such as improper waste disposal and agricultural runoff, significantly influence water quality. Concentrations of CO_3^{2-}, HCO_3^-, and alkalinity were determined by titration using 0.02N H_2SO_4 and a Tarson Auto-titrator (Model: Titer Top 25). Major ions, including Fluoride (F^-), Chloride (Cl^-), Sulfate (SO_4^{2-}), Phosphate (PO_4^{3-}), Nitrate (NO_3^-), Sodium (Na^+), Potassium (K^+), Ammonium (NH_4^+), Magnesium (Mg^{2+}), and Calcium (Ca^{2+}), were analyzed using ion chromatography (IC), calibrated with Merck standards, and results were reported with an analytical precision of ±5%. Samples were diluted 10 times with Milli-Q water (18.2 MΩ resistivity). For trace metal analysis, 60 ml aliquots were analyzed for Pb, Zn, As, Cd, Ni, B, Al, Cr, Mn, and Fe using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The Water Quality Index (WQI) for the study was calculated using a weighted arithmetic method, where key water quality parameters such as pH, dissolved oxygen, turbidity, and major ions were assigned respective weights based on their relative importance. The individual parameter values were compared to standard water quality guidelines, and the WQI was computed by aggregating these weighted values. This method provided an overall index that categorizes water quality into various classes, enabling a comprehensive assessment of water health in the Henval catchment. The physicochemical analysis of 34 water samples from the Henval catchment in Tehri Garhwal, Uttarakhand, revealed overall good water quality across different sources. While, some spring water samples exhibited slightly higher concentrations of nitrate and sulfate, the majority maintained excellent quality, with WQI values typically between 0-50, indicating minimal contamination and largely natural processes. Stream water samples were also found to be of good quality, meeting key standards such as pH (6.5–8.5) and DO (> 5 mg/L), with only minor variations attributable to localized factors. River water samples similarly fell within the good quality range, with slightly elevated levels of nutrients such as nitrate and phosphorus, though these remained within a minor range that does not significantly impact overall quality.

Collectively, the findings demonstrate that the water quality in the Henval catchment is well-sustained, with only minor deviations, underscoring the region's generally favourable conditions for water resources. The water quality analysis revealed that the river samples exhibited acceptable levels of nitrate and phosphate, indicating effective natural filtration and limited anthropogenic impact. The relatively low turbidity, TDS and minimal contaminants reflect a balanced aquatic ecosystem, supported by sustainable land use and controlled discharge of effluents. These findings suggest that both natural processes and responsible human activities are contributing positively to maintaining the water quality within the catchment. This highlights the effectiveness of current management practices and emphasizes the importance of continuing integrated water management strategies to sustain and enhance these favourable conditions.

Keywords: *Spring, hydrochemistry, Henval catchment, Uttarakhand, water scarcity, water quality index*

ISHVAR – INFORMATION SYSTEM OF HIMALAYAN SPRINGS FOR VULNERABILITY ASSESSMENT AND REJUVENATION

Deepak Singh Bisht[1], Chhaya Bhatia[2], Sumit Kumar[1], Chandra Mohan Singh Adhikari, Sugam Samriti Banchta[2] and Soban Singh Rawat[1]

[1]National Institute of Hydrology, Roorkee, India
[2]ESRI India Pvt. Ltd., India
[*]Corresponding author e-mail: dsbisht.ae@gmail.com

Springs are vital lifelines in the Indian Himalayan Region (IHR), serving as crucial sources of freshwater for biodiversity, local ecosystems, and human populations. These natural water outlets play a pivotal role in sustaining the region's rich biodiversity, providing essential hydration to flora and fauna. They are integral to the survival of numerous species, many of which are endemic to the Himalayas, thus maintaining ecological balance and supporting unique habitats. Springs also serve as a cornerstone for local ecosystems, replenishing soil moisture and sustaining streams and wetlands, which are critical for agricultural and forest health.

For local communities, springs are indispensable for daily needs such as drinking water, irrigation, and livestock rearing. Many Himalayan villages, lacking large-scale water infrastructure, rely exclusively on springs for their sustenance. In addition to their practical utility, these water sources hold cultural and spiritual significance, often regarded as sacred by the local populace. However, the overexploitation of spring water and climate change pose threats to their sustainability. Protecting and restoring these springs through community-driven management and scientific interventions is essential to ensure water security and preserve the delicate ecological balance of the Himalayan region. Springs are, therefore, not just natural resources but lifelines for both biodiversity and humanity in the IHR.

In Himachal Pradesh, a predominantly rural Himalayan state, water demand in rural areas surpasses that of urban regions. Traditional water sources, especially springs, are crucial for meeting water needs, particularly for marginalized communities, amid imbalances in water supply and consumption. Recognizing their importance, the Planning Commission (now NITI Aayog) emphasized the establishment of a traditional water resources cell to develop and safeguard these resources in light of climate change and anthropogenic pressures. NITI Aayog's report, "*Inventory and Revival of Springs in the Himalayas for Water Security*," called for a web-enabled database to map Himalayan springs. The development of a Web-GIS based Information System facilitates data visualization and analysis, empowering stakeholders with valuable information for decision-making. This tool enhances transparency, collaboration, and informed decision-making in water resource management efforts. In response, a Purpose Driven Study (PDS) titled "*Web GIS-based Spring Inventory for Vulnerability Assessment and Hydro-geological Investigation of Selected Springs in the Ravi Catchment, Himachal Pradesh*" was initiated in August 2017 under the aegis of National Hydrology Project (NHP).

Keeping the above discussion in view, a study was formulated for the Chamba district of Himachal Pradesh, which constitutes a significant part of the Ravi River Basin, to develop a digital database of springs. This paper provides a brief overview of the following three key objectives derived from the detailed study undertaken: i) Creation of web-enabled database of the springs emerging in the catchment based on extensive inventory of physical and hydro-

chemical characteristics, ii) Mapping of vulnerable springs using hot-spot analysis, and iii) To build capacity among the local stakeholders through creating para-hydrogeologists for conserving and managing the springs. A comprehensive digital database was developed as a WebGIS portal using ESRI ArcGIS Enterprise, named ISHVAR (Information System of Himalayan Springs for Vulnerability Assessment and Rejuvenation). This portal hosts data on over 900 springs across the Chamba district, encompassing more than 30 parameters that provide a detailed overview of the springs' characteristics, along with vulnerability assessments. The ISHVAR portal is designed to support policymakers and planners by providing critical insights to inform the design of future developmental activities. Furthermore, it facilitates the allocation of resources for spring rejuvenation initiatives, contributing to enhanced water security in the region. This digital platform serves as a vital tool for sustainable water resource management in the Himalayan context.

The exercise carried out in herein has laid a strong foundation for conducting a comprehensive nationwide census, demonstrating the feasibility and value of systematically collecting and analyzing large-scale data. The methodologies and frameworks established have not only streamlined data collection processes but have also highlighted the importance of detailed, region-specific insights for effective planning and management. Building on this groundwork, the forthcoming information from the national census will be hosted on a dedicated portal, ensuring accessibility and transparency. This platform will enable the general public, stakeholders, researchers, and decision-makers to utilize the data for diverse applications, ranging from policy formulation and academic studies to strategic planning and community-level interventions, fostering evidence-based decision-making across sectors.

Keywords: *Springs, ISHVAR, Indian Himalayan Region, Chamba, Ravi River basin*

HYDROGEOCHEMICAL CHARACTERIZATION OF HOT SPRINGS IN THE BHAGIRATHI VALLEY, UTTARAKHAND, INDIA: INSIGHTS INTO GEOTHERMAL RESOURCES AND RECHARGE MECHANISMS

Sumit Rana[1], S.S. Rawat[2*], Akashay Verma[2], Tripti Muguli[2], Amit Pandey[2] and D.S. Bagri[1]

[1]HNB Garhwal University, Srinagar, Uttarakhand, India
[2]National Institute of Hydrology, Roorkee, India
[*]Corresponding author e-mail: ssrawat.nihr@gov.in

Hot or thermal springs are natural geological and geothermal phenomena, where water heated by the earth's internal heat emerges at the ground surface through the major faults and fractures. These hot springs form through the combination of geothermal, geological, and tectonic processes, where water seeps into the earth's crust through the fracture and porous rock formations, where it absorbs the heat from the surrounding geothermal sources before it emerges as thermal springs. The quality of heated water is influenced by several factors, including the rate/residence time of subsurface water circulation, the temperature of heat sources, rock alteration, and the degree of mixing with the cold groundwater from surrounding areas. Geological Survey of India (GSI) identified about 381 hot springs in different states of India in different geothermal provinces. Hot springs that occurred in the Himalayan geothermal province represent the areas prone for geothermal activity. The Himalayan geothermal belt extended from Ladakh to Arunachal Pradesh and spread over the length of approximately 1500 km. All the hot springs in the Himalayan region fall in the Central Himalayan geothermal belt of Northwestern Himalayan geothermal sub-provinces. Three main thermal occurrences in this belt are Punga, Chumatahng, Sidhu, and Nubra of Ladakh; Manikaran, Kosal, Bashist, and Tattapani of Himachal Pradesh; Tapoban, Yamunotri, Gangnani, and Gaurikund of Uttarakhand. GSI reports that eighty-two hot springs are located throughout Uttarakhand. The Ganga River Basin and the Kali River Basin are the two main basins where all of the hot springs are located. Forty hot springs identified in the various River valleys associated with the Ganga River basin are Tons, Yamuna, Bhagirathi, Bhilangna, Mandakini, Alaknanda, Dhauli, and Pinder valleys. Twenty-five hot springs were identified throughout many river valleys associated with the Ramganga Valley, Goriganga Valley, Dhauliganga Valley, and Darma Valley. The present study area lies in the Bhagirathi Basin from Chinyalisour to Harsil. Bhagirathi Valley is known for the occurrence of hot springs near Gangnani area. We identify a total of six hot springs in the study area namely in the places Joti, Gangnani, Jhaya, Bukki, and Matli in Uttarkashi district of Uttarakhand. Some physical parameters like Temp, pH, EC, TDS, etc. have been analyzed during the fieldwork in post-monsoon, 2024, while water samples of hot springs for Major ions, heavy metals, and isotopes were collected for analysis in the National Institute of Hydrology (NIH), Roorkee laboratory. These hot springs are visited by a large number of pilgrims every year as a part of religious belief. The hot spring at Gangnani occurs on the left bank of the Bhagirathi River. Its water emerges from sericite-biotite schist interbedded with granite gneiss from about 100 m above the river bed. Its water has a temperature of 59°C, a discharge rate is about 31 LPM, pH of 6.6, electrical conductivity of 1475 µS/cm and TDS of 950 ppm. Bhukki hot spring is located on the road to Gangotri about 25 km upstream of Aungi on the right bank of the Bhagirathi River, the temperature of the hot water is 34°C and the discharge rate is 15 LPM. It emerges through the gneiss belonging to the Central Crystalline. Its water has a pH of 6.10, Electrical Conductivity of 1118 µS/cm and TDS of

794 ppm. Two hot springs were reported in Jhaya towards 5 km upstream of Bhukki, these springs have temperatures of 48°C and 42°C, pH, EC, TDS are 8.00 and 8.14, 464 µS/cm and 545 µS/cm, 332 ppm and 387 ppm, respectively. These springs also emerge from the right bank of the Bhagirathi River. Joti hot spring is located 4 km upstream of Gangnani hot spring on the left bank of the Bhagirathi River. The temperature of thermal water is 57°C and has pH, EC, TDS, 6.67,1848 µS/cm, and 1200 ppm, respectively. Based on the water chemistry, hot springs can be grouped into three water types: Na- Cl, Ca- HCO_3 and Na- HCO_3. The majority of these six hot springs in the Bhagirathi Valley are categorized as Na-HCO_3 type of water based on the physical and chemical characteristics examined in this study. To understand the water recharge mechanism in the study area, isotopic samples of hot springs were employed. The finding highlights the importance of these springs as geothermal resources and cultural heritage places and also offers important insights into the hydrogeological processes.

Keywords: *Hot water springs, thermal springs, hydro-geochemistry, isotope analysis, Bhagirathi valley, recharge mechanism*

COMMUNITY LED SPRINGSHED MANAGEMENT IN MEGHALAYA, INDIA

Gunanka D.B.[1], Gaurav Singh[2*] and Jillianda Kharjana[3]

[1]*Department of the Planning Investment Promotion and Sustainable Development, State GIS & UAV Centre Government of Meghalaya, India*
[2]*State GIS & UAV Centre, Meghalaya Basin Development Authority, Meghalaya, India*
[3]*Water Resources, Meghalaya Basin Development Authority, Meghalaya, India*
[*]*Corresponding author e-mail: iitr.gauravsingh@gmail.com*

Springs are the primary water source in Meghalaya and 80% of its villages relying heavily on springs for drinking water and irrigation this reliance is threatened by anthropogenic activities like mining, unsustainable agriculture, and forest resource extraction, which have led to the drying up or reduced water discharge of about 50% of these springs. Rural communities perceive changes in spring quality as indicative of broader shifts in climate and land use patterns. Despite efforts to address these issues, comprehensive information on all springs in the state, which is under the 6th Schedule and where land is owned by communities, remains incomplete, highlighting the critical need for community involvement. Rainfall patterns have also shifted, showing increased overall rainfall within a narrower timeframe. This has led to the reduction in spring discharge and consequently the drying up of springs during the dry season. This in turn has led to significant challenges for women in these villages, forcing them to travel farther to fetch water. According to a rough estimate, almost all springs have witnessed a decline in discharge due to land use changes, including increased diversion, pumping, groundwater exploitation, pollution of surface and ground waters, degradation of natural recharge areas, and possibly climate change. The increasing demand for water and decreasing supply, attributed to these factors, underscores the necessity to comprehend the accessibility of water resources, specifically focusing on springs which have limited resources. Hence, the concept of springshed management was introduced with the intention of establishing a baseline data for future references and for identifying critical springs that require intervention also understanding their flow patterns, and developing management strategies to ensure that water resources are preserved for future generations. A holistic approach has been implemented to map, management, and monitoring of springs. This approach includes the development of a Spring Manual and the training to Village Community Facilitators, Green Volunteers, engineers, and GIS experts, along with additional master trainers. Advanced technologies such as GIS, Global Navigation Satellite System, and other mobile applications are also being utilized. Over 55,000 springs has been mapped under External Aided Projects (EAPs). Furthermore, a central dashboard has been developed to monitor spring-related activities in real time. The initiative of spring mapping and springshed management is regarded as the best approach for several reasons. Despite significant investments in natural resource management, the lack of baseline data was a major challenge. Spring mapping addressed this gap by providing crucial information on springs, enabling the development of sustainable management plans. Various parameters were captured, including discharge measurements, water quality indicators such as pH, TDS, EC, salinity and temperature, along with socio-economic factors. Monthly monitoring of critical springs supports Springshed Development activities aimed at enhancing spring discharge through recharge interventions. Community engagement played a key role in this approach with conducting Participatory Rural Appraisal (PRA) exercises followed by hydrogeological field survey and interventions. This involvement has empowered local communities in decision-

making regarding conservation efforts. The approach is also cost-effective, ensuring efficient resource utilization while achieving significant benefits in water management. Furthermore, it provides government departments with a clearer understanding of on-the-ground realities, improving water management strategies and interventions. Geospatial Technology has incorporated to create a visual representation of spring locations, accessible via the Dashboards which enhanced accessibility to data on spring locations, water quality, and flow rates, aiding decision-making processes.

Spring mapping and springshed management was initially conceptualized by the Institute of Natural Resources, Meghalaya under the Meghalaya Basin Development Authority (MBDA). This concept was subsequently expanded through various externally funded projects, including the JICA funded MegLIFE, the World Bank-funded Meghalaya Community-Led Landscapes Management Project (MCLLMP), and the IFAD-funded Meghalaya Livelihoods and Access to Markets Project (MLAMP). The initiative has now been further advanced through the new EAP which is MegARISE project, funded by KfW, which focuses on the rejuvenation of two key catchments in the state: Umiew catchment in East Khasi Hills and the Ganol catchment in West Garo Hills. Within the MegLIFE project, under Meghalaya Basin Development Authority (MBDA) implementing comprehensive springshed management activities for more than 1700 springs across 500 villages in Meghalaya, aiming to enhance water security and sustainability through targeted watershed and recharge interventions under Soil and water conservation activity. The activity was built on extensive collaboration with various partners to achieve its objectives and ensure a comprehensive approach to springshed management. Key partnerships included those with CHIRAG, ACWADAM, PRASARI, and PSI, which provided essential technical expertise and support for springshed interventions. These training initiatives enhanced the knowledge and skills of participants across the water sector, fostering effective collaboration and cohesive implementation of springshed management efforts. In total 168 Detailed Technical Reports by MLSC partners and MegLIFE staff has further enriched the knowledge base required for future conservation efforts. Collectively, these initiatives have laid a strong foundation for ensuring the long-term viability of Meghalaya's springs and their critical role in sustaining rural communities.

Springs are a vital and irreplaceable resource for rural communities in Meghalaya, providing essential water for drinking, agriculture, and daily life. However, climate change, deforestation, over extraction, and pollution pose significant threats to their sustainability. Community-led initiatives for spring mapping and sustainable springshed management are critical to ensuring the long-term availability of these water sources. By leveraging collective action, traditional knowledge, and modern technology, rural communities in Meghalaya are taking ownership of their water resources and building a more sustainable future. This community-based water resource management model offers valuable lessons for other regions facing similar challenges in managing natural water resources. Springs are a vital and irreplaceable resource for rural communities in Meghalaya, providing essential water for drinking, agriculture, and daily life. Community led efforts to map springs and develop sustainable springshed management strategies are crucial to ensuring the long-term availability of spring water. Through collective action, community knowledge, and the integration of modern technology, rural communities in Meghalaya are taking ownership of their water resources and working toward a more sustainable future.

Keywords: *Community, springs, springshed, geospatial technology, Meghalaya*